MONITORING AND EVALUATION OF SMOLT MIGRATION IN THE COLUMBIA BASIN VOLUME XVI

Survival and Transportation Effects for Migrating Snake River Hatchery Chinook Salmon and Steelhead: Historical Estimates From 1996-2003

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Other Publications in this Series

Volume I: Townsend, R. L., J. R. Skalski, and D. Yasuda. 1997. Evaluation of the 1995 predictions of run-timing of wild migrant subyearling chinook in the Snake River Basin using program RealTime. Technical Report (DOE/BP-35885-11) to BPA, Project 91-051-00, Contract 91-BI-91572.

Volume II: Townsend, R. L., J. R. Skalski, and D. Yasuda. 1998. Evaluation of the 1996 predictions of run-timing of wild migrant subyearling chinook in the Snake River Basin using program RealTime. Technical Report (DOE/BP-91572-2) to BPA, Project 91-051-00, Contract 91-BI-91572.

Volume III: Townsend, R. L., J. R. Skalski, and D. Yasuda. 2000. Evaluation of the 1997 predictions of run-timing of wild migrant yearling and subyearling chinook and sockeye in the Snake River Basin using program RealTime. Technical Report to BPA, Project 91-051-00, Contract 91-BI-91572.

Volume IV: Burgess, C., R. L. Townsend, J.R. Skalski, and D. Yasuda. 2000. Evaluation of the 1998 predictions of the run-timing of wild migrant yearling and subyearling chinook and steelhead, and hatchery sockeye in the Snake River Basin using program RealTime. Technical Report to BPA, Project 91-051-00, Contract 96BI-91572.

Volume V: Burgess, C., J.R. Skalski. 2000. Evaluation of the 1999 predictions of the run-timing of wild migrant yearling and subyearling chinook salmon and steelhead trout, and hatchery sockeye salmon in the Snake River Basin using program RealTime. Technical Report to BPA, Project 91-051-00, Contract 96BI-91572.

Volume VI: Burgess, C., J.R. Skalski. 2000. Evaluation of the 2000 predictions of the run-timing of wild migrant chinook salmon and steelhead trout, and hatchery sockeye salmon in the Snake River Basin, and combined wild and hatchery salmonids migrating to Rock Island and McNary Dams using program RealTime. Technical Report to BPA, Project 91-051-00, Contract 96BI-91572.

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Volume VIII: Skalski, J.R. and R.F. Ngouenet. 2001. Comparison of the RPA testing rules provided in the 2000 Federal Columbia River Power System (FCRPS) Biological Opinion with new test criteria designed to improve the statistical power of the biological assessments. Technical Report to BPA, Project 91-051-00, Contract 96BI-91572.

Volume IX: Burgess, C., J.R. Skalski. 2001. Evaluation of the 2001 Predictions of the Run-Timing of Wild and Hatchery-Reared Migrant Salmon and Steelhead Trout migrating to Lower Granite, Rock Island, McNary, and John Day Dams using Program Real-Time. Technical Report to BPA, Project 91-051-00, Contract 96BI-91572.

Volume X: Burgess, C., J.R. Skalski. 2002. Evaluation of the 2002 Predictions of the Run-Timing of Wild and Hatchery-Reared Migrant Salmon and Steelhead Trout migrating to Lower

Granite, Rock Island, McNary, and John Day Dams using Program Real-Time. Technical Report to BPA, Project 91-051-00, Contract 96BI-91572.

Volume XI: Burgess, C., J.R. Skalski. 2004. Evaluation of the 2003 Predictions of the Run-Timing of Wild and Hatchery-Reared Migrant Salmon and Steelhead Trout migrating to Lower Granite, Rock Island, McNary, and John Day Dams using Program Real-Time. Technical Report to BPA, Project 91-051-00, Contract 00004134.

Volume XII: Townsend, Richard L., C. Burgess, J.R. Skalski. 2005. Evaluation of the 2004 Predictions of the Run-Timing of Wild and Hatchery-Reared Salmon and Steelhead Smolt to Rock Island, Lower Granite, McNary, John Day and Bonneville Dams using Program Real-Time. Technical Report to BPA, Project 91-051-00, Contract 00004134.

Volume XIII: Griswold, Jim, R.L. Townsend, J.R. Skalski. 2006. Evaluation of the 2005 Predictions of the Run-Timing of Wild and Hatchery-Reared Migrant Salmon and Steelhead Trout migrating to Lower Granite, Rock Island, McNary, John Day and Bonneville Dams using Program Real-Time. Technical Report to BPA, Project 91-051-00, Contract 00025093.

Volume XIV: Griswold, Jim, R.L. Townsend, J.R. Skalski. 2006. Evaluation of the 2006 Predictions of the Run-Timing of Wild and Hatchery-Reared Salmon and Steelhead Smolt at Rock Island, Lower Granite, McNary, John Day and Bonneville Dams using Program RealTime. Technical Report to BPA, Project 91-051-00, Contract 00025093.

Volume XV: Griswold, J., R. L. Townsend, and J. R. Skalski. 2007. Evaluation of the 2007 Predictions of the Run-Timing of Wild and Hatchery-Reared Salmon and Steelhead Smolts to Rock Island, Lower Granite, McNary, John Day, and Bonneville Dams using Program RealTime. Volume XV in the Monitoring and Evaluation of Smolt Migration in the Columbia River. Technical report to BPA, Project 91-051-00, Contract 29676.

Other Publications Related to this Series

Other related publications, reports and papers available through the professional literature or from the Bonneville Power Administration (BPA) Public Information Center - CKPS-1, P.O. Box 3621, Portland, OR 97208.

1997

Townsend, R. L., D. Yasuda, and J. R. Skalski. 1997. Evaluation of the 1996 predictions of run timing of wild migrant spring/summer yearling chinook in the Snake River Basin using program RealTime. Technical Report (DOE/BP-91572-1) to BPA, Project 91-051-00, Contract 91-BI-91572.

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1995

Townsend, R. L., P. Westhagen, D. Yasuda, and J. R. Skalski. 1995. Evaluation of the 1994 predictions of the run-timing of wild migrant yearling chinook in the Snake River Basin. Technical Report (DOE/BP-35885-8) to BPA, Project 91-051-00, Contract 87-BI-35885.

1994

Skalski, J. R., G. Tartakovsky, S. G. Smith, P. Westhagen, and A. E. Giorgi. 1994. Pre-1994 season projection of run-timing capabilities using PIT-tag databases. Technical Report (DOE/BP-35885-7) to BPA, Project 91-051-00, Contract 87-BI-35885.

1993

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Smith, S. G., J. R. Skalski, and A. E. Giorgi. 1993. Statistical evaluation of travel time estimation based on data from freeze-branded chinook salmon on the Snake River, 1982-1990. Technical Report (DOE/BP-35885-4) to BPA, Project 91-051-00, Contract 87-BI-35885.

Preface

Project 91-051 was initiated in response to the Endangered Species Act (ESA) and the subsequent 1994 Council Fish and Wildlife Program (FWP) call for regional analytical methods for monitoring and evaluation. This project supports the need to have the "best available" scientific information accessible to the BPA, fisheries community, decision-makers, and public by analyzing historical tagging data to investigate smolt outmigration dynamics, salmonid life histories and productivity, and providing real-time analysis to monitor outmigration timing for use in water management and fish operations of the hydrosystem. Primary objectives and management implications of this project include: (1) to address the need for further synthesis of historical tagging and other biological information to improve understanding and identify future research and analysis needs; (2) to assist in the development of improved monitoring capabilities, statistical methodologies and software tools to aid management in optimizing operational and fish passage strategies to maximize the protection and survival of listed threatened and endangered Snake River salmon populations and other listed and non-listed stocks in the Columbia River Basin; (3) to develop better analysis tools for monitoring evaluation programs; and (4) to provide statistical support to the Bonneville Power Administration and the Northwest fisheries community.

The following report presents historical estimates of survival and transportation effects for hatchery PIT-tagged salmon released in the Snake River Basin from 1996 to 2003. Reported measures are calculated on an annual basis for basin-wide release groups. Estimates of the overall smolt-to-adult return ratio (SAR) are reported, as well as of juvenile inriver survival from Lower Granite Dam to Bonneville Dam, survival from Bonneville back to Bonneville, and adult survival from Bonneville to Lower Granite. Transportation effects are reported in two ways: the transport-inriver (T/I) ratio, and differential post-Bonneville mortality (D). Estimates of T/I and D are reported both on a systemwide basis incorporating all transport dams analyzed, and on a dam-specific basis. For a given release group, transportation effects are estimated only for transportation from dams where at least 5,000 smolts from the release group were transported. Results are presented separately for hatchery spring Chinook salmon, summer Chinook salmon, and steelhead.

Abstract

In 2005, the University of Washington developed a new statistical model to analyze the combined juvenile and adult detection histories of PIT-tagged salmon migrating through the Federal Columbia River Power System (FCRPS). This model, implemented by software Program ROSTER (River-Ocean Survival and Transportation Effects Routine), has been used to estimate survival and transportation effects on large temporal and spatial scales for PIT-tagged hatchery spring and summer Chinook salmon and steelhead released in the Snake River Basin from 1996 to 2003. Those results are reported here. Annual estimates of the smolt-to-adult return ratio (SAR), juvenile inriver survival from Lower Granite to Bonneville, the ocean return probability from Bonneville to Bonneville, and adult upriver survival from Bonneville to Lower Granite are reported. Annual estimates of transport-inriver (T/I) ratios and differential post-Bonneville mortality (D) are reported on both a systemwide basis, incorporating all transport dams analyzed, and a dam-specific basis. Transportation effects are estimated only for dams where at least 5,000 tagged smolts were transported from a given upstream release group. Because few tagged hatchery steelhead were transported in these years, no transportation effects are estimated for steelhead. Performance measures include age-1-ocean adult returns for steelhead, but not for Chinook salmon. Additional results are available online at `http://www.cbr.washington.edu/trends/roster/php`.

Annual estimates of SAR from Lower Granite back to Lower Granite averaged 0.71% with a standard error (SE) of 0.18% for spring Chinook salmon from the Snake River Basin for tagged groups released from 1996 through 2003, omitting age-1-ocean (jack) returns. For summer Chinook salmon from the Snake River Basin, the estimates of annual SAR averaged 1.15% (SE=0.31%). Only for the release years 1999 and 2000 did the Chinook SAR approach the target value of 2%, identified by the NPCC as the minimum SAR necessary for recovery. Annual estimates of SAR for hatchery steelhead from the Snake River Basin averaged 0.45% (SE=0.11%), including age-1-ocean returns, for release years 1996 through 2003. For release years when the ocean return probability from Bonneville back to Bonneville could be estimated (i.e., 1999 through 2003), it was estimated that on average approximately 86% of the total integrated mortality for nontransported, tagged hatchery spring and summer Chinook, and 74% for steelhead, occurred during the ocean life stage (i.e., from Bonneville to Bonneville). This suggests that additional monitoring and research efforts should include the ocean and estuary environment.

Annual estimates of the systemwide T/I are weighted averages of the dam-specific T/I ratios for each transport dam (with $\geq$ 5,000 tagged fish transported), weighted by the probabilities of being transported at each dam. The systemwide T/I compares the observed SAR under the existing transportation system with the expected SAR if the transportation system had not been operated. Estimates of 1.0 indicate that the systemwide transportation program has no effect on SAR, while estimates $>$ 1.0 indicate that the transportation program increases SAR. Excluding the 2001 release group, the geometric mean of the systemwide T/I estimates for hatchery spring Chinook salmon

from the Snake River Basin was 1.15 (SE=0.03) for release years 1997 through 2003. The geometric mean of the systemwide T/I estimates for hatchery summer Chinook salmon from the Snake River Basin was 1.28 (SE=0.13) for release years 1997 through 2000 and 2003. Estimates were much higher for the 2001 release groups. These estimates reflect transportation from Lower Granite and/or Little Goose for most release years, depending on the number of tagged smolts actually transported at each dam during each release year.

Differential post-Bonneville mortality (D) is the ratio of post-Bonneville survival to Lower Granite Dam of transported fish to that of nontransported ("inriver") fish. Excluding the 2001 release year, the geometric mean of the D estimates for hatchery spring Chinook salmon from the Snake River Basin was 1.00 (SE=0.09) for release years 1997 through 2003. For hatchery summer Chinook salmon from the Snake River Basin, the geometric mean of the D estimates was 1.32 (SE=0.27) for release years 1997 through 2000 and 2003. These estimates reflect transportation from Lower Granite and/or Little Goose, depending on the number of tagged smolts actually transported at each dam during each release year. Approximately half the point estimates of D for both spring and summer Chinook salmon were 1.0 or greater, indicating that for those release groups, transported fish did not have lower ocean and adult survival than nontransported fish. For those years with estimates of $D < 1.0$, the systemwide T/I estimates were always ≥ 1.0, indicating that despite lower ocean and adult survival of transported fish, transportation did not lower SAR overall.

Executive Summary

Objectives

We present annual estimates of the following performance measures for hatchery spring and summer Chinook salmon and steelhead released in the Snake River Basin from 1996 to 2003:

- Inriver survival between Lower Granite Dam and Bonneville Dam for smolts ("juveniles");
- Inriver survival between Bonneville Dam and Lower Granite Dam for adults, categorized in two ways:
  - For all adults returning from a given release group ("By release group");
  - For all adults migrating upstream in a given calendar year ("By return year").
- Ocean return probability (i.e., probability of returning from Bonneville as a juvenile to Bonneville as an adult) for nontransported ("inriver") and transported fish separately;
- Smolt-to-adult return ratio (SAR) from Lower Granite back to Lower Granite for the release group (i.e., transported and nontransported fish combined);
- Transportation effects, including
  - Dam-Specific transport-inriver ratio (T/I);
  - Systemwide T/I, combining effects of transportation at all transport dams with transport groups analyzed (generally, Lower Granite and Little Goose);
  - Differential post-Bonneville mortality, D, the ratio of survival from Bonneville as a juvenile to Lower Granite as an adult of transported smolts to that of nontransported smolts, including both a dam-specific D and a systemwide D that incorporates all transport dams analyzed.

Estimates are made on large temporal and spatial scales. Annual estimates are based on regional release groups of PIT-tagged salmonids composed of individual releases of hatchery fish in either the Clearwater Basin, the Snake River Basin outside the Clearwater Basin, or the entire Snake

River Basin (both groups above pooled). Estimates for hatchery spring Chinook salmon, summer Chinook salmon, and steelhead are presented separately. Inference from the results reported here is to the hatchery populations studied; results from the hatchery fish analyzed here should not be used to make inference to wild fish or to species and runs not explicitly included. Detections from the age-1-ocean age class and older age classes were used in estimating smolt survival through the lower river reaches for both Chinook salmon and steelhead. However, reported performance measures that relate to adult returns (e.g., SAR, T/I, D) represent only age-2-ocean and age-3-ocean adults for Chinook salmon. Reported performance measures for steelhead include the age-1-ocean adults, as well as older age classes. Additional results for Chinook salmon that include the age-1-ocean adults are available online at `http://www.cbr.washington.edu/trends/roster/php`.

Methods

Data Methods

Tagging and detection data were downloaded from the PTAGIS database for hatchery spring and summer Chinook salmon and steelhead released as smolts in the Snake River Basin upstream of Lower Granite Dam from 1996 to 2003. Data for release years 1996 to 2002 were downloaded from the PTAGIS database on 12 June 2006, and data for the 2003 release year were downloaded on 12 December 2006. Release groups were defined by species, run, release area, and release year. For each release group, transportation effects were analyzed for dams where at least 5,000 tagged smolts were transported. Detection histories combining juvenile and adult detections were compiled using University of Washington software PitPro, which is publicly available online at `http://www.cbr.washington.edu/paramest/pitpro/`.

Statistical Methods

Each set of PIT-tag detection data was analyzed with a release-recapture likelihood model that jointly analyzes juvenile and adult PIT-tag data to estimate inriver juvenile survival, ocean return probabilities, adult upriver survival, transportation rates, and transportation effects on survival. The model has been peer-reviewed and appears in Buchanan and Skalski (2007). This statistical model incorporates PIT-tag detection and juvenile transportation, and accounts for known removals of tagged fish from the migrating population. Unique adult survival probabilities are estimated for transported and nontransported fish, and for adults returning in different calendar years. This statistical model was implemented by Program ROSTER (River-Ocean Survival and Transportation Effects Routine), developed by the University of Washington and publicly available at `http://www.cbr.washington.edu/paramest/roster/`. Program ROSTER fits the likelihood model using numerical estimation techniques, and provides maximum likelihood estimates and associated estimated standard errors of model parameters and performance measures.

Performance measures of interest are defined in terms of the model parameters. Estimated performance measures are calculated from estimates of model parameters, and uncertainty measures on the performance measure estimates (i.e., standard errors) are estimated from the variance-covariance matrix generated by the model-fitting process. Consequently, all performance measures are maximum likelihood estimators (MLEs) based on the invariance property of MLEs (Norden 1972). Performance measures of transportation effects (e.g., transport-inriver ratios) were peer-reviewed in Buchanan, Skalski, and Smith (2006), and performance measures of survival were peer-reviewed in Buchanan and Skalski (2007).

The analysis approach taken in this report is based on a comprehensive modeling perspective that incorporates the relationship between data from successive migratory life stages. The joint analysis of juvenile and adult PIT-tag detection data enables concurrent estimation of survival and transportation parameters through different life stages, and avoids model misspecification that may result from separate single life-stage models. Performance measures are defined and estimated using first principles, and variance estimates are calculated directly from the model-fitting process using well-established maximum likelihood estimation methods.

Data Summary

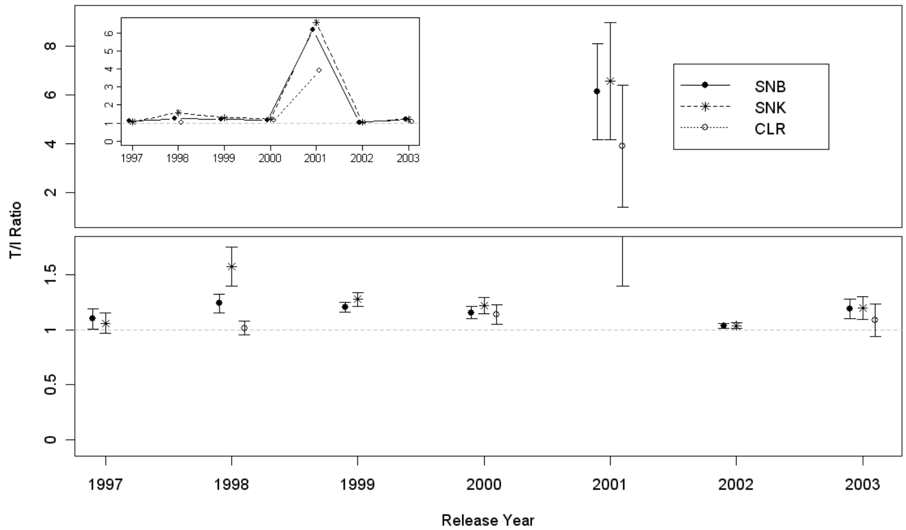
A total of 3,602,547 tagged fish were included in the 40 release groups analyzed here, with release groups ranging in size from 20,433 for spring Chinook salmon released in the Clearwater Basin in 1997 to 304,850 for spring Chinook released in the Snake River Basin (including the Clearwater) in 2003. A total of 535,536 transported fish were analyzed, with transport groups ranging in size from 5,034 for summer Chinook salmon released in the Snake River Basin in 1999 to 47,604 for spring Chinook salmon from the Snake River Basin released in 2003. Most transported smolts were transported from Lower Granite Dam (LGR), with the remaining transportation occurring from Little Goose Dam (LGS). No Lower Monumental or McNary transport groups were analyzed, because too few tagged smolts were transported at these dams. No steelhead transport groups were analyzed because of the low numbers of PIT-tagged hatchery steelhead transported in these years.

Results

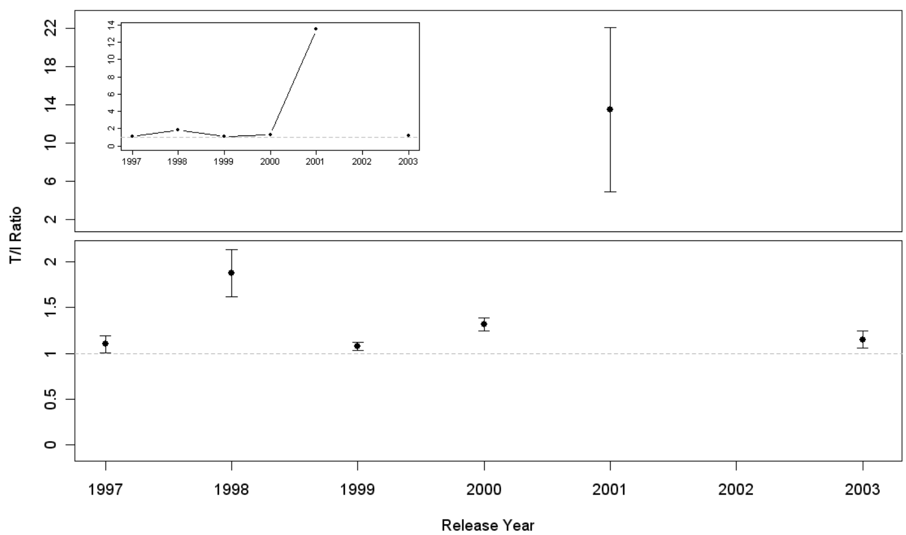
Hatchery Spring and Summer Chinook

The geometric average of the systemwide T/I (R_{SYS}) estimates was 1.15 (standard error [SE]=0.03) for Snake River Basin spring Chinook over release years 1997 to 2003, excluding the estimate for the low flow year 2001 (Figure 1a). Estimates of T/I were generally higher for spring Chinook from the Snake River (excluding the Clearwater), and lower for spring Chinook from the Clearwater. For all three groups of spring Chinook, the estimate of the systemwide T/I for 2001 was much higher than 1, but also had high uncertainty (Figure 1a). The geometric average of the systemwide T/I estimates for summer Chinook from the Snake River Basin was 1.28 (SE=0.13) over the release years 1997 to 2003, excluding the 2001 estimate and also the 2002 estimate, when no summer Chinook transportation effects were analyzed because too few tagged summer Chinook salmon were transported. As with spring Chinook, the 2001 estimate of the systemwide T/I for summer Chinook was considerably greater than 1 and had high uncertainty (Figure 1b).

Point estimates of the systemwide D (D_{SYS}) were generally lower than estimates of the systemwide T/I for both spring and summer Chinook. The (geometric) average of the systemwide D estimates for spring Chinook salmon from the Snake River Basin was 1.00 (SE=0.09) over release years 1997 to 2003 (excluding 2001). Estimates of D were generally higher for spring Chinook from the Snake River (excluding the Clearwater) and lower for spring Chinook from the Clearwater (Figure 2a). The geometric average of the systemwide D estimates for summer Chinook from the Snake River Basin was 1.32 (SE=0.27) over the release years 1997 to 2003, excluding 2002 when no summer Chinook transportation effects were analyzed and also excluding the 2001 estimate (Figure 2b). Estimates of the systemwide D for 2001 spring Chinook from all three release areas were both high and uncertain, relative to other years. No estimate of D was available for 2001 summer Chinook because of low numbers of adult detections from that release year. Point estimates of juvenile inriver survival of nontransported fish from Lower Granite Dam to Bonneville Dam were generally smaller than point estimates of D for both spring and summer Chinook salmon (Figures 3a and 3b).

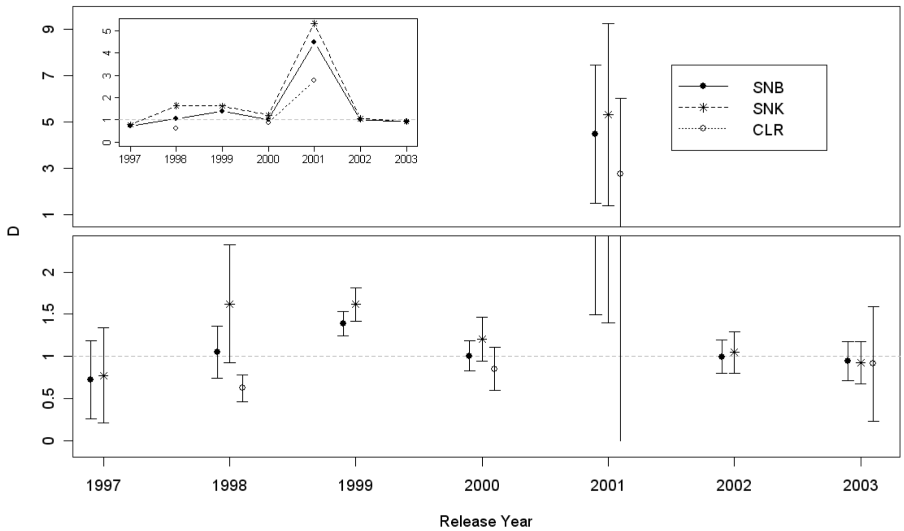


(a) T/I, Spring Chinook

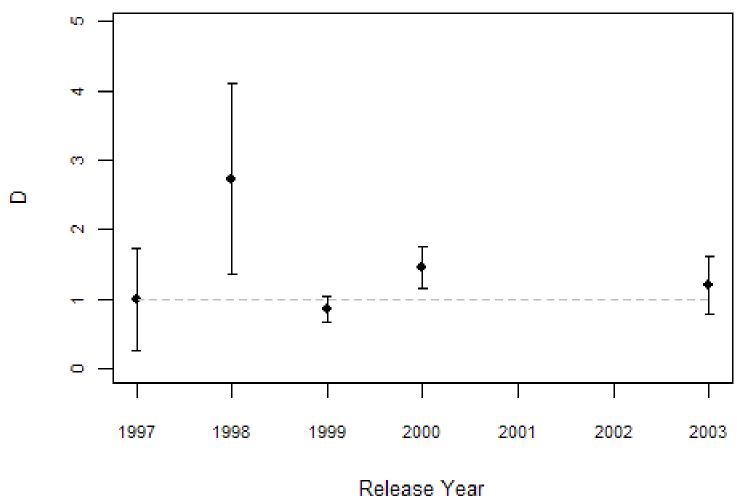


(b) T/I, Summer Chinook

Figure 1: Point estimates and 95% confidence intervals for systemwide T/I for spring (a) and summer (b) Chinook salmon. Split plots were used to accommodate the different scales of the estimates. Estimates do not include jacks. The release area abbreviations for spring Chinook are: CLR = Clearwater River, SNK = Snake River (excluding the Clearwater), and SNB = Snake River Basin (equivalent to CLR and SNK combined). The horizontal lines at T/I=1 are shown for comparison. Only transportation effects from dams with at least 5,000 tagged smolts transported in a given release year are included.

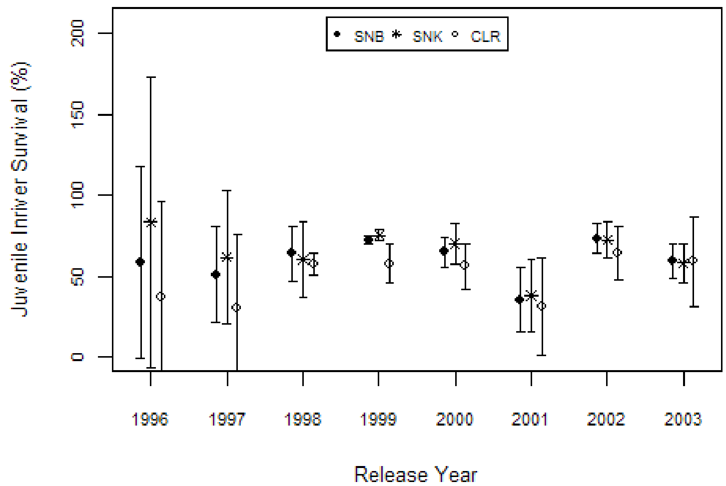


(a) D, Spring Chinook

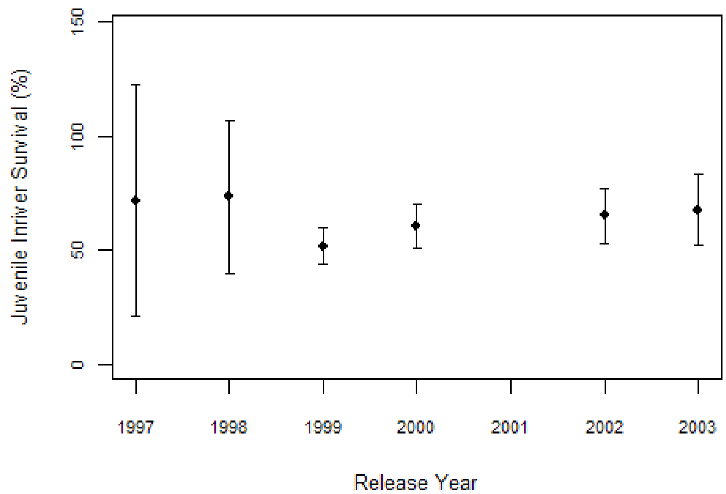


(b) D, Summer Chinook

Figure 2: Point estimates and 95% confidence intervals for systemwide D for spring (a) and summer (b) Chinook salmon. A split plot was used to accommodate the different scales of the estimates for spring Chinook. Estimates do not include jacks. The release area abbreviations for spring Chinook are: CLR = Clearwater River, SNK = Snake River (excluding the Clearwater), and SNB = Snake River Basin (equivalent to CLR and SNK combined). The horizontal lines at D=1 are shown for comparison. Only transportation effects from dams with at least 5,000 tagged smolts transported in a given release year are included. The 2001 estimate for summer Chinook is missing because too few adults were detected from that release group to fit the full ROSTER model.



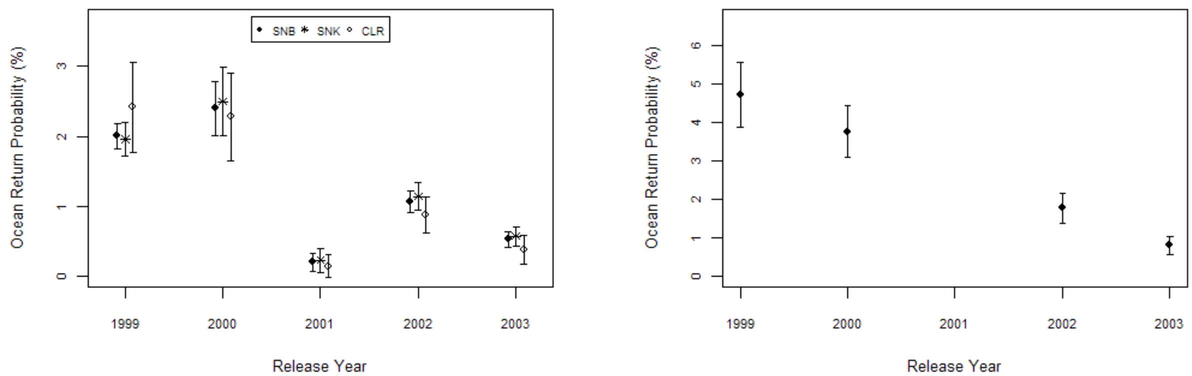
(a) Juvenile Inriver Survival, Spring Chinook



(b) Juvenile Inriver Survival, Summer Chinook

Figure 3: Point estimates and 95% confidence intervals for juvenile inriver survival for spring (a) and summer (b) Chinook salmon. The release area abbreviations for spring Chinook are: CLR = Clearwater River, SNK = Snake River (excluding the Clearwater), and SNB = Snake River Basin (equivalent to CLR and SNK combined). The spring Chinook CLR estimates for 1996 and 1997 were extrapolated from estimated survival to McNary on a per-river kilometer and per-project basis, respectively. The spring Chinook SNK estimate for 1996 was extrapolated from estimated survival to McNary on a per-site basis. The summer Chinook estimate for 1998 was extrapolated from survival to John Day on a per-site basis. Estimates for summer Chinook were unavailable for the 1996 and 2001 release years because too few nontransported summer Chinook adults were detected from those release groups.

The (arithmetic) average of estimated ocean return probability (i.e., survival from Bonneville back to Bonneville) for nontransported fish (O_{NT}; excluding jacks) over release years 1999 to 2003 was 1.24% (SE=0.42%) for spring Chinook from the Snake River Basin, 1.28% (SE=0.42%) for spring Chinook from the Snake River (excluding the Clearwater), and 1.22% (SE=0.48%) for spring Chinook from the Clearwater (Figure 4a). For summer Chinook from the Snake River Basin, the average estimate of ocean return probability for nontransported fish (excluding jacks) was 2.77% (SE=0.90%) over release years 1999, 2000, 2002, and 2003 (Figure 4b). No estimate of the ocean return probability was available for 2001 summer Chinook because too few nontransported adults were detected from the 2001 release group.

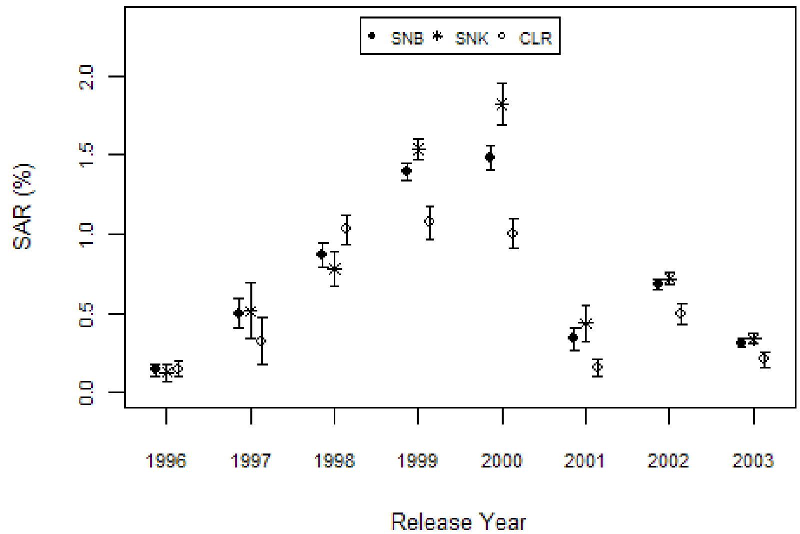


(a) Ocean Return Probability, Spring Chinook

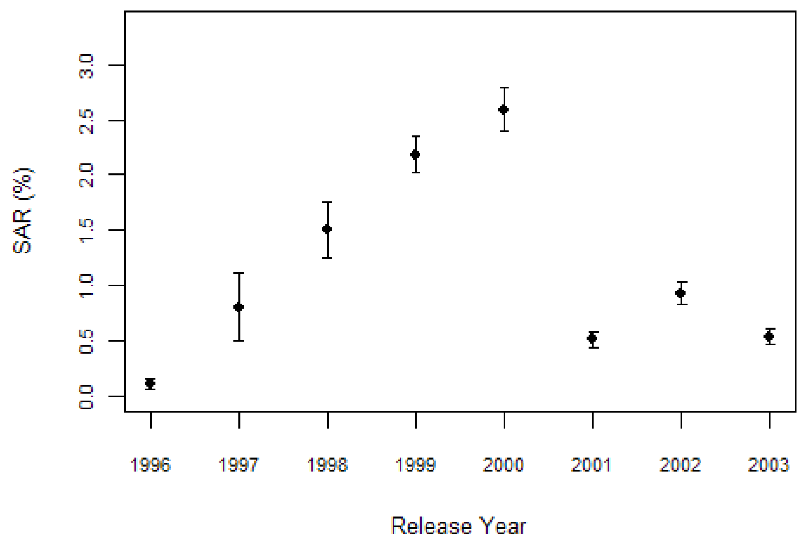
(b) Ocean Return Probability, Summer Chinook

Figure 4: Point estimates and 95% confidence intervals for the ocean return probability for tagged hatchery nontransported spring (a) and summer (b) Chinook salmon. Estimates do not include jacks. The release area abbreviations for spring Chinook are: CLR = Clearwater River, SNK = Snake River (excluding the Clearwater), and SNB = Snake River Basin (equivalent to CLR and SNK combined). No estimate is available for 2001 for summer Chinook because too few adults were detected from that release group.

Estimated SAR from Lower Granite to Lower Granite, including both transported and nontransported fish but excluding jacks, averaged 0.71% (SE=0.18%) for tagged spring Chinook from the Snake River Basin for release years 1996 to 2003, 0.78% (SE=0.21%) for tagged spring Chinook from the Snake River (excluding the Clearwater) for the same release years, and 0.55% (SE=0.15%) for spring Chinook from the Clearwater for the same release years (Figure 5a). For tagged hatchery summer Chinook from the Snake River Basin, the average estimated SAR was 1.15% (SE=0.31%) over release years 1996 to 2003 (Figure 5b). These estimates do not include jacks.



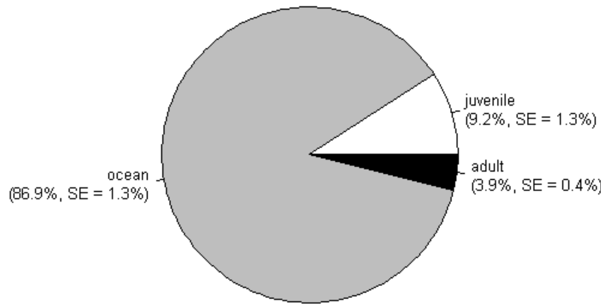
(a) SAR, Spring Chinook



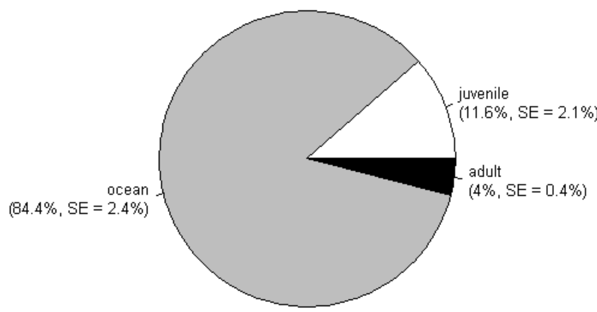
(b) SAR, Summer Chinook

Figure 5: Point estimates and 95% confidence intervals for SAR for tagged hatchery nontransported spring (a) and summer (b) Chinook salmon. Estimates do not include jacks. The release area abbreviations for spring Chinook are: CLR = Clearwater River, SNK = Snake River (excluding the Clearwater), and SNB = Snake River Basin (equivalent to CLR and SNK combined).

Total integrated mortality is a measure of the contributions to overall mortality from the different life stages that is invariant to the order of those life stages. The largest proportion of total integrated mortality between passing Lower Granite as a smolt and returning to Lower Granite as an adult for nontransported fish came from the ocean life stage for both spring and summer Chinook salmon. For tagged spring Chinook salmon from the Snake River Basin, the ocean life stage (i.e., Bonneville to Bonneville) accounted for an average of 87% (SE=1.3%) of the total integrated mortality between passing LGR as a smolt and returning to LGR as an adult (non-jack) for smolts released from 1999 to 2003 (Figure 6a). For tagged summer Chinook salmon, the ocean life stage accounted for an average of 84% (SE=2.4%) of the total integrated mortality from 1999 to 2003, excluding 2001 when there was insufficient data (Figure 6b). The implication for spring and summer Chinook is that the ocean life stage is more significant in determining SAR than either the juvenile or the adult freshwater migrations through the hydrosystem.



(a) Spring Chinook



(b) Summer Chinook

Figure 6: The average estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for spring Chinook salmon from the Snake River Basin (a) and summer Chinook salmon (b), from 1999 to 2003. Estimates for 2001 are not included in the summer Chinook results (b) because too few nontransported adults were detected from that release group.

Hatchery Steelhead

Too few tagged hatchery steelhead were transported during the release years 1996 to 2003 to analyze transportation effects on hatchery steelhead. Thus, no estimates of T/I or D are available for steelhead. Estimates of the ocean return probability (from Bonneville as a smolt back to Bonneville) and SAR (from Lower Granite back to Lower Granite) include the age-1-ocean age class.

Juvenile inriver survival was estimated for all release years from 1997 to 2003, excluding 2001. Neither the 1996 nor the 2001 release year had sufficient adult detections to estimate juvenile inriver survival for those release years. For the 6 years with estimates, the (arithmetic) average of the juvenile inriver survival estimates from Lower Granite to Bonneville was 35.4% (SE=4.2%) for hatchery steelhead (Figure 7).

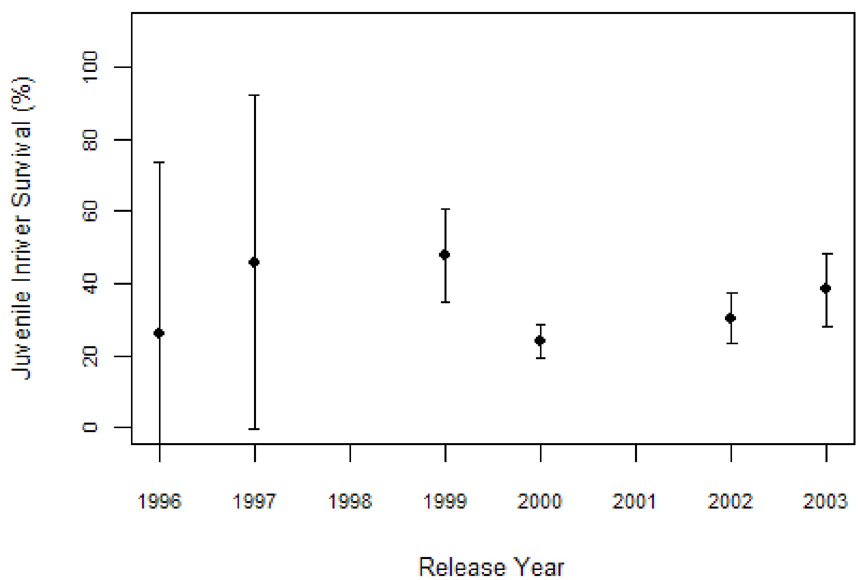
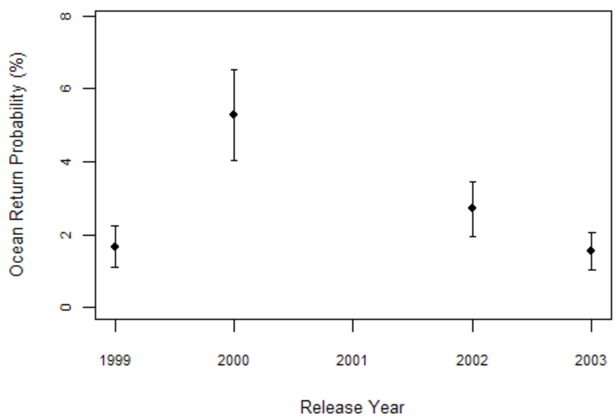


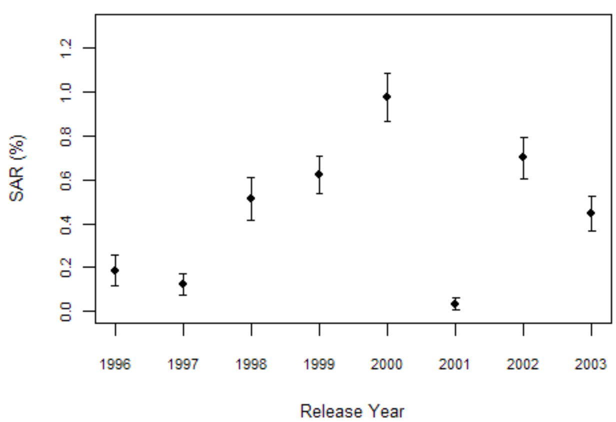
Figure 7: Estimated juvenile inriver survival for hatchery steelhead ($\widehat{S_J}$), with 95% confidence intervals. Estimates were unavailable for 1998 and 2001 because too few nontransported adults were detected from these release groups. The 1996 estimate was extrapolated on a per-river kilometer basis from estimated survival to McNary.

Estimated ocean return probability (i.e., survival from Bonneville to Bonneville) for tagged hatchery steelhead from the Snake River Basin ranged from 1.67% (SE=0.29%) for the 1999 release group to 5.28% (SE=0.63%) for the 2000 group (Figure 8a), with an (arithmetic) average of 2.80% (SE=0.87%) for release years 1998, 1999, 2002, and 2003. There was insufficient data to estimate the ocean return probability for the 2001 release group. Estimated values of SAR from Lower Granite to Lower Granite ranged from 0.03% (SE=0.01%) for the 2001 release group to 0.98% (SE=0.06%)

for the 2000 release group (Figure 8b), with an average estimate of 0.45% (SE=0.11%) from 1996 to 2003.



(a) Ocean Return Probability



(b) SAR

Figure 8: Point estimates and 95% confidence intervals for the ocean return probability (a) and SAR (b) for tagged hatchery nontransported steelhead from the Snake River Basin. No estimate of ocean return probability is available for 2001 steelhead because too few adults were detected from that release group.

The largest contribution to the total integrated mortality between passing Lower Granite as a smolt and returning to Lower Granite as an adult came from the ocean life stage for tagged hatchery steelhead. On average for the years 1999, 2000, 2002, and 2003, the ocean life stage accounted for approximately 74% (SE=3.7%) of the total integrated mortality between passing LGR as a smolt and returning to LGR as an adult (including age-1-ocean fish) (Figure 9). The implication for steelhead is that mortality occurs in the ocean at a higher intensity than during either the juvenile

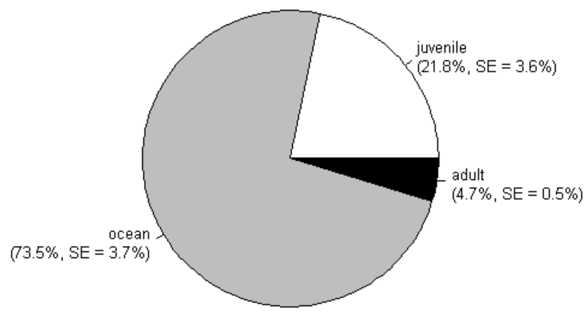


Figure 9: The average estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for tagged hatchery non-transported steelhead from the Snake River Basin, from 1999 to 2003. Estimates for 2001 are not included because of limitations of the data.

or the adult freshwater migrations through the hydrosystem.

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Acknowledgments

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Chapter 1

Introduction

1.1 Background

Since 1987, Passive Integrated Transponder (PIT) tags have been used to gather information about salmonid migrations in the Columbia and Snake rivers, in an effort to assess the effectiveness of mitigation actions intended to offset the impact of hydroelectric dams on the survival of migrating salmonids. Much interest has focused on the efficacy of the smolt transportation program run by the U.S. Army Corps of Engineers at Lower Granite, Little Goose, Lower Monumental, and McNary dams. Also of interest are performance measures such as ocean survival and the smolt-to-adult return ratio (SAR).

Until the mid-1990s, PIT-tag detections of juveniles (smolts) were available at only a few upstream dams, and detections of adults were available only at Lower Granite Dam. Additionally, numbers of tagged smolts were typically small, averaging a total of approximately 88,000 tagged per year from 1987 to 1995 in the Snake River Basin upstream of Lower Granite reservoir. The limited PIT-tag detection data resulted in statistical analyses that focused on ratio estimators of heuristically defined performance measures. Efforts to adjust tag counts for imperfect tag detection at dams, multiple transport dams, and the variable migration pathways open to smolts, resulted in complex statistical methods developed outside a comprehensive modeling framework (e.g., Sandford and Smith 2002; Berggren et al. 2005). Model-based analyses of PIT-tag data were limited to single life stages, reflecting either only juvenile data or only adult data. Much discussion has been centered on the validity of alternative statistical methods, competing definitions of performance measures, and populations of fish studied.

Starting in the mid-1990s, additional dams were equipped with PIT-tag detection capabilities, with the juvenile bypass systems at six dams on the Snake and lower Columbia rivers wired for detection by 1999. Detection in adult fish ladders became available at Bonneville Dam in the late 1990s, and at McNary and Ice Harbor dams several years later. With increased detection capability and greater numbers of PIT-tagged smolts released, it is now possible to analyze the detection data from the entire migration through the hydrosystem in a statistical likelihood-based approach that models the complete passage histories of the tagged fish (Buchanan and Skalski 2007). Benefits of using a comprehensive likelihood-based modeling approach developed from first principles include a holistic conceptualization of the processes that produce the data, avoidance of possible model misspecification that may arise from a multi-stage heuristic approach, precise identification of underlying assumptions, the ability to clearly define performance measures in a probabilistic framework using model parameters, and model-based estimates of uncertainty in the point estimates of those performance measures. The modeling framework also inherently accounts for detection probabilities that are less than 100%, and allows treatment effects of various mitigation actions (e.g., transportation) to be incorporated directly into the model and estimated concurrently with inriver survival parameters. This concurrent estimation allows the correlation between parameters to be appropriately incorporated into standard error estimates of derived performance measures.

In 2005, Columbia Basin Research at the University of Washington developed modeling software called Program ROSTER, or River-Ocean Survival and Transportation Effects Routine. Program ROSTER, publicly available at `http://www.cbr.washington.edu/paramest/roster/`, implements a multinomial likelihood model to analyze joint juvenile and adult detection data from PIT-tagged smolts migrating through the Federal Columbia River Power System (FCRPS). The ROSTER model analyzes the patterns of juvenile and adult detections for each fish to estimate survival through the migratory life stages, and uses information on transported fish to estimate transportation effects on ocean and adult survival. Program ROSTER uses all fish in the release group, including fish that were not detected or that were known to be removed from the population (e.g., entered the sampling room at a dam). Detections from fish that were singly-bypassed or multiply-bypassed as smolts, as well as those that were undetected, are used to estimate survival. All detections of returning adults, including the age-1-ocean fish ("jacks"), are used to estimate smolt survival in the lower river reaches. This analysis approach differs from existing approaches, e.g., those used by the National Marine Fisheries Service (NMFS, developed in Sandford and Smith 2002) and the Comparative Survival Study (CSS, described in Berggren et al. 2007). Thus, results from Program ROSTER are expected to be somewhat different from existing estimates.

The model parameters for survival and transportation effects are used to estimate a variety of performance measures, including several measures of transport-inriver ratios (T/I ratios; Buchanan et al. 2006) and differential post-Bonneville mortality (D), SAR, juvenile inriver survival, the ocean return probability, and adult upriver survival. Point estimates and standard errors are reported for each performance measure. Performance measures may be defined to include the performance of the age-1-ocean age class, or they may represent only age-2-ocean and older age classes. For this report, performance measures for Chinook salmon exclude the age-1-ocean returns, while performance measures for steelhead include age-1-ocean returns by convention (Williams et al. 2005).

The availability of data sets including large numbers of both juvenile and adult PIT-tag detections and the use of the ROSTER model make it possible to easily make annual estimates of important performance measures. The ROSTER model is best used to estimate performance measures on large spatial and temporal scales. These estimates reflect large-scale processes in survival, and complement estimates on smaller spatial or temporal scales that are produced using alternative methods.

1.2 Objectives

We will present historical annual estimates of the following performance measures for hatchery spring and summer Chinook salmon and steelhead released in the Snake River Basin from 1996 to 2003:

- Inriver survival between Lower Granite Dam and Bonneville Dam for smolts ("juveniles");
- Inriver survival between Bonneville Dam and Lower Granite Dam for adults, categorized in two ways:
  - For all adults returning from a given release group ("By release group");
  - For all adults migrating upstream in a given calendar year ("By return year").
- Ocean return probability (i.e., probability of returning from Bonneville as a juvenile to Bonneville as an adult) for nontransported ("inriver") and transported fish separately;
- Smolt-to-adult return ratio (SAR) from Lower Granite as a juvenile to Lower Granite as an adult for a given release group (transported and nontransported fish combined);
- Transportation effects, including
  - Dam-Specific transport-inriver ratio (T/I);
  - Systemwide T/I, combining effects of transportation at all transport dams with analyzed transport groups (generally, Lower Granite and Little Goose);
  - Differential post-Bonneville mortality, D, the ratio of survival from Bonneville as a juvenile to Lower Granite as an adult of transported smolts to that of nontransported smolts, including both a dam-specific D and a systemwide D that incorporates all analyzed transport dams.

Annual estimates will be based on regional release groups of PIT-tagged salmonids composed of individual releases of hatchery fish in either the Clearwater Basin, the Snake River Basin outside the Clearwater Basin, or the entire Snake River Basin (both groups above pooled). Estimates for hatchery spring Chinook salmon, summer Chinook salmon, and steelhead will be presented separately. Inference from the results reported here is to the hatchery populations studied; results from the hatchery fish analyzed here should not be used to make inference to wild fish or to species and runs not explicitly included. Results for wild fish will be reported in a separate report. Performance measures that relate to adult returns (i.e., SAR, the ocean return probability, adult upriver survival, T/I, and D) will be reported here only for age-2-ocean and older age classes for spring and summer Chinook salmon, but will be reported for all returning age classes (including age-1-ocean) for steelhead. The results reported here for hatchery fish, as well as details on data collection, preparation, and analysis, are provided online at `http://www.cbr.washington.edu/trends/roster.php`. Additional results for spring and summer Chinook salmon that include the age-1-ocean fish, and results for steelhead that exclude the age-1-ocean fish, are also available at this website.

Chapter 2

Methods

2.1 Data Collection and Preparation Methods

2.1.1 Data Used

We analyzed annual PIT-tagged release groups composed of hatchery fish released in the Snake River Basin upstream of Lower Granite Dam from 1996 to 2003. Spring Chinook salmon, summer Chinook salmon, and steelhead were analyzed separately. The release groups analyzed were categorized by species, run, release area (described below), and release year. For these fish, release year was equivalent to migration year (MY). The data requirements of the ROSTER model demand large release groups because of low return rates from the ocean, so it was necessary to pool fish from individual releases made at separate release sites to form the annual release groups. We were able to analyze spring Chinook salmon from the Clearwater River separately from the rest of the Snake River Basin. We also analyzed data pooled from these two groups. Release groups of spring Chinook salmon are characterized by their release areas: Clearwater River Basin (release area CLR), Snake River Basin excluding the Clearwater (release area SNK, referred to as "Snake River"), and the Snake River Basin including the Clearwater (release area SNB). Summer Chinook salmon and steelhead were analyzed for the Snake River Basin (release area SNB). Details on the EPA reaches composing the different release areas are available online at `http://www.cbr.washington.edu/trends/roster.php`. Release sites, identified by river kilometer (RKM), are detailed for each release group in Appendix C.1.

Annual transport groups within each release group were composed of all fish transported from a particular dam within the release year, regardless of transport date. Low return rates from the ocean precluded analysis of small transport groups. Transportation effects can be reasonably estimated only if sufficient adults return from both the transport and the nontransport groups. Ideally, each group should consist of at least 100 returning adults with adequate returns in each age class. With overall ocean return probabilities ranging from 0.5% to 5%, approximately 5,000 transported smolts are needed for each transport group. Thus, only transport groups with at least 5,000 smolts transported were analyzed. Smaller transport groups were treated as known removals, and their detection histories were censored at their transport dam (i.e., these fish were not used to estimate survival after passing the transport dam). Transportation effects were not estimated for dams with transport groups smaller than 5,000, and transportation from these dams was not included in systemwide performance measures.

Juvenile PIT-tag detection was available at four detection sites in all years: Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMO), and McNary (MCN). Additionally, detections at Bonneville (BON) were available starting in 1997, and detections at John Day (JD) were available starting in 1998. Some release groups experienced either low numbers of juvenile detections at BON or low numbers of adult detections of nontransported fish. For these release groups, it was impossible to estimate smolt detection probabilities at BON and survival to BON. In these cases, it was necessary to omit BON from the juvenile detection sites, and estimate juvenile inriver survival to BON by extrapolating estimates of juvenile inriver survival to MCN or JD, as available. Extrapolation was performed on a per-detection site, per-project, or per-RKM basis, depending on goodness-of-fit (see Appendix E.1.1). Extrapolation was performed outside the ROSTER model.

Adult PIT-tag detection became available at an increasing number of dams during the study period. Until 2000, only LGR had reliable adult detection. From 2000 to 2002, both BON and LGR had adult detection capability; after 2002, BON, MCN, Ice Harbor (IH), and LGR all had adult PIT-tag detection capability. Thus, the number of adult detection sites modeled increased throughout the study (Table C.6).

Detections of PIT tags are also available from the towed PIT-tag detection array operated by the National Marine Fisheries Service (NMFS) in the Columbia River estuary. These detections may be used to estimate juvenile survival to Bonneville. However, the ROSTER model used to analyze the data for this report uses adult detections from the fish ladders to estimate juvenile survival, so the towed array detections are unnecessary in the general case. The joint probability of survival of smolts from Bonneville to the towed array and detection there is typically low (1% - 3%), so including the towed array detections in the analysis would require estimation of extra parameters from little extra data. For this reason, detections from the towed array were omitted from the analyses.

Detections of all returning adults were used in estimating parameters of the release-recapture model, including jacks but not mini-jacks. We use the term "jack" to refer to all age-1-ocean fish. Because adult data are classified by return year (equivalently by ocean age class), including adult data from jacks does not affect estimation of adult parameters for older age classes, but does provide maximum information on the juvenile migration. Performance measures such as SAR are defined using estimates of juvenile, ocean, and adult parameters, and may be calculated either for all returning adults including jacks, or only for non-jack adults. The performance measures presented here are reported for non-jack adults for spring and summer Chinook salmon, but are reported for all adults (including age-1-ocean fish) for steelhead. This mirrors the approach taken elsewhere (e.g., Berggren et al. 2005), and is based on observations that age-1-ocean fish do not contribute largely to Chinook salmon returns, but do contribute heavily to overall steelhead returns. Estimated performance measures both excluding and including jacks are reported on the Columbia Basin Research (CBR) webpage at `http://www.cbr.washington.edu/trends/roster.php`.

2.1.2 Acquiring Data

PIT-tag release and recapture data for release years 1996 - 2002 were downloaded in June 2006 from the PTAGIS database, maintained by the Pacific States Marine Fisheries Commission. PIT-tag release and recapture data for release year 2003 were downloaded in December 2006, to include age-3-ocean adult detections. For these fish, release year was equivalent to migration year. The PTAGIS database was accessed via Telnet. Details of the queries used to download the data are available online at the CBR webpage.

Appropriate tagged smolts were identified by their release date; species, run, and rear-type; migration year; and release site (EPA reach; see the CBR webpage). By specifying the migration year and restricting attention to hatchery fish, we were confident that tagged fish were smolts that migrated during the year of their release. Because both juvenile and adult PIT-tag detections were required, we did not restrict the observation dates in the Interrogation Summary from PTAGIS (see the CBR webpage for PTAGIS queries), but instead used all observations of each PIT-tagged fish.

2.1.3 Preparing Data for Analysis

The University of Washington software used to analyze the data, Program ROSTER, requires data in the form of detection histories. A detection history is a sequence of codes indicating the nature of the observation of a tagged fish at each detection site, combining both juvenile and adult detection sites. Each detection site in the study is represented by a single field in the detection history. The detection history indicates the sites where the fish was detected and where it was not detected, where the fish was transported (if at all), and the fish's ocean age class if it was detected as an adult. Each fish in the release group has its own detection history.

The raw PIT-tag detection data downloaded from PTAGIS must be converted to joint juvenile and adult detection histories. This was done using University of Washington software PitPro, which determines the appropriate detection history for each fish based on release information, observed PIT-tag detections, any tag-recovery or mortality information, and decision rules regarding disposition after detection. The decision rules used by PitPro are described briefly here and in more detail at `http://wiki.cbr.washington.edu/pittag/index.php/PitPro_Manual`. PitPro is publicly available online at `http://www.cbr.washington.edu/paramest/pitpro/`.

A juvenile fish may pass a dam (or detection site) by one of several routes: over the spillway, through the juvenile bypass system, or through the powerhouse (turbines). Additionally, a fish that enters the juvenile bypass system at a transport dam may be collected for transportation, returned directly to the river, or diverted to the sampling room before being either collected for transportation or returned to the river. Adult fish pass dams by way of fish ladders; it is possible that juvenile fish descend dams by fish ladders, although this is thought to be uncommon. If a PIT-tagged fish enters via a route monitored for PIT tags, the tag may be detected as the fish passes the dam. Most fish detected at a dam are detected multiple times there, because monitored routes typically have more than one detection monitor. Some routes (e.g., spillway, turbines) have no detection monitor, so fish passing via these routes are undetected at the dam. Routes that typically have PIT-tag detection monitors include the juvenile bypass flumes that return juveniles to the river, the raceway to transport trucks or barges (for juveniles), the sampling room, and the fish ladder. PitPro assigns the code for the dam's field in the detection history based on the particular PIT-tag monitors that detected the tag at the dam. Smolts that are transported are distinguished from fish that enter the sampling room or are returned to the river. Fish that enter the sampling room at a dam are classified as "known removals" at that dam; the records of known-removal fish are right-censored at the removal dam (i.e., the detection history indicates removal at the removal dam, and does not reflect subsequent detections).

Converting joint juvenile and adult detection data to detection histories requires decision rules on how to distinguish between juvenile and adult detections, how to handle adult fallback, and how to identify and deal with detections from residualizing juveniles. Some PIT-tag detectors monitor passage routes that are used by both juvenile and adults; in these cases, the location of a detection within a dam is insufficient for identifying the life stage of the detected fish. For these detectors (e.g., in fish ladders), PitPro uses the assumed migration year of tagged fish (noted in PTAGIS data) to distinguish between juvenile and adult detections. Fish detected during their assumed migration year are classified as juveniles (smolts), while fish detected after their assumed migration year are classified as adults. Adults may descend a dam after passing it (i.e., "fallback"), either accidentally or purposely. Adults that re-ascend a dam after fallback may be detected both before and after fallback, and thus may have more than one sequence of PIT-tag detections past the dam. In cases of fallback, PitPro uses the final upriver route determined from the PIT-tag data. Thus, adult upriver "survival" parameters include the probability of successfully reascending dams after any fallback. Finally, because the ROSTER model used to analyze these data is inappropriate for release groups that include large numbers of residualizing juveniles (i.e., juveniles that overwinter during their outmigration), PitPro removes fish from the release group if they are observed on known juvenile detectors after the end of their migration year. This policy is used for both spring and summer Chinook salmon and steelhead. Because steelhead are known to exhibit juvenile residualization, especially in low-flow or drought years, an additional safeguard against including residualizing juveniles is incorporated, whereby fish are removed from the release group if they are observed on any detector in the spring of the year following their migration year. In particular, steelhead detected before 1 June of the year following their outmigration are removed, regardless of the location of the detection (e.g., fish ladder detections). Steelhead detected after 1 June of the year following their outmigration are considered age-1-ocean adults.

In addition to detection of tags at the dams, PIT-tag data from the PTAGIS database include mortality and recapture data, when available. The mortality data report known mortalities of tagged fish, including both natural mortality and handling mortality. PitPro treats handling mortalities as known removals from the migrating population. Mortalities from bird predation (Table 2.1) are considered to be natural mortalities, and are not treated as known removals; thus, mortalities from bird predation contribute to the survival estimate in the reach containing the tag recovery site. The recapture data report tags of fish that were recovered at hatcheries or in fisheries; recaptured fish were not returned to the migrating population, and tags in the recaptured data file are classified by PitPro as known removals at the dam most recently passed by the tagged fish. Recaptures at the release sites are ignored.

Table 2.1: PTAGIS recovery sites of PIT-tags from bird predation. Tags recovered at these sites are treated as natural mortalities, and are not labeled as “known removals” (i.e., detection histories not right-censored).

PTAGIS Site Code	**Site Name**
3MILIS	Three Mile Canyon Island
BADGEI	Badger Island
CRESIS	Crescent Island
ESANIS	East Sand Island
FOUNDI	Foundation Island
IS18	Island 18
LMEMIS	Little Memaloose Island
LMILIS	Little Miller Island
RICEIS	Rice Island
RICHIS	Richland Island

PitPro performs several types of error-checking, including looking for fish that were observed on known juvenile detectors outside the migration year. It also flags tags that were recovered or removed before reaching the first detection site (Lower Granite Dam), and tags with observations that are out of sequence. For example, a smolt that was detected at Lower Monumental Dam and then later detected in the juvenile bypass system at Lower Granite Dam has out-of-sequence observations, and is treated as an error. Erroneous records are removed from the release group. Records of tags that are labeled “transport” but are detected downriver as juveniles are right-censored at the supposed transport dam, rather than removed as errors.

More detail on the configuration of PitPro used to process the data is provided online at http://www.cbr.washington.edu/trends/roster.php. PitPro itself is publicly available online at http://www.cbr.washington.edu/paramest/pitpro/.

In addition to the decision rules used by PitPro described above, specialized processing of the data was sometimes necessary to deal with anomalous or problematic data. In particular, because we cannot estimate transportation effects from small transport groups, we censored all detection histories for transport groups composed of fewer than 5,000 tagged smolts at the transport site. This minimum transport group size was selected based on observed ocean return probabilities ranging from 0.5% to 5%. Censoring smaller transport groups means that we treated these small transport groups as known removals at the transport site. We were unable to estimate transportation effects or adult upriver survival for censored transport groups. Additionally, detection histories for fish from very small adult age classes were censored at their final juvenile detection, because reliable ocean and adult inference cannot be made based on only a few fish. Finally, for several release groups, low numbers of juvenile detections at BON prevented estimation of the detection probability at BON. In these cases, BON was removed from the set of juvenile detection sites (see Section 2.1.1 for more details on the resulting analysis).

2.2 Statistical Methods

2.2.1 Release-Recapture Model

Each data set was analyzed with a statistical release-recapture likelihood model (i.e., the ROSTER [River-Ocean Survival and Transportation Effects Routine] model) that jointly analyzes juvenile and adult PIT-tag data to estimate juvenile survival, ocean return probabilities, perceived adult survival, and transportation probabilities (Appendix D; Buchanan 2005; Buchanan and Skalski 2007). The ROSTER model incorporates PIT-tag detection and juvenile transportation, and accounts for known removals of tagged fish from the migrating population. Unique adult survival probabilities are estimated for transported and nontransported fish, and for adults returning in different calendar years. Estimates of juvenile survival in the upper reaches (e.g., through McNary or John Day) coincide with estimates from the Cormack-Jolly-Seber (CJS; Cormack 1964; Jolly 1965; Seber 1965) statistical model. Estimates of juvenile survival through lower reaches (e.g., from John Day to Bonneville) are based on adult return data, and so may differ slightly from estimates based on detections at the Estuary Towed PIT-Tag Detection Array operated by NOAA-Fisheries. Differences between estimates based on adult returns and estimates based on the estuary towed array are expected to be minimal.

Performance measures of interest are defined in terms of the model parameters. Estimated performance measures are calculated from estimates of model parameters, and sampling errors for the performance measures (i.e., standard errors) are calculated using the Delta Method (Seber 1982, pp. 7-9).

The ROSTER model (Buchanan and Skalski 2007) was implemented by Program ROSTER, software that was developed by the University of Washington and is publicly available online at `http://www.cbr.washington.edu/paramest/roster/`. Program ROSTER fits the likelihood model using numerical estimation techniques, and provides maximum likelihood estimates and standard errors of model parameters and performance measures.

In cases where the full ROSTER model could not be implemented because of sparse adult detection data or low numbers of nontransported fish, the CJS model was used to estimate juvenile survival to the transportation dams. These estimates were combined with counts of adult detections to calculate heuristic estimates of SAR, T/I ratios, and adult upriver survival.

Because Program ROSTER models the entire hydrosystem migration between passing Lower Granite as a smolt and returning there as an adult, it depends on many assumptions. All analysis methods, including those that are not likelihood-based, depend on assumptions to some extent. The ROSTER model is basically a modified CJS model, with branching to account for transportation and different adult age classes. Thus, the assumptions of the ROSTER model are based on the assumptions of the CJS model. The main assumptions of the ROSTER model are as follows: **(A1)** All nontransported smolts have equal probabilities of survival, detection, and transportation at juvenile sites. **(A2)** All nontransported smolts have common age-specific ocean return probabilities, and common age-specific adult survival and detection probabilities, regardless of detection at previous juvenile or adult sites. **(A3)** All smolts transported from a given dam have common probabilities of subsequent survival and detection (as adults), regardless of previous detections. **(A4)** Detection at an adult site has no effect on subsequent survival or detection. **(A5)** The fate of each tagged individual is independent of the fate of all other tagged individuals. **(A6)** Tagging and release have no effect on subsequent survival, detection, or transportation probabilities, and there is no tag loss after release. **(A7)** All tags are correctly identified, and the detection histories (e.g., censored, transported) are correctly assigned. Additionally, in order to make inference from the model results to the untagged population (i.e., the population-at-large), it must be assumed that the composition of the release groups represents the composition of the untagged population-at-large fish.

The assumptions relating to common survival and detection probabilities may be violated by forming release groups that are pooled either over space (i.e., the release location) or over time (e.g., pooling all release groups from the year). In addition, fish that volitionally migrate early in the season may have different survival probabilities than fish that migrate later in the season. The result of pooling to form the release group may then be heterogeneous survival or detection parameters. Heterogeneous parameters have little effect on the point estimates of survival, resulting in survival estimators that are unbiased for the weighted averages of the actual survival probabilities across the release group. This has been noted for the general case by several researchers (e.g., Carothers 1973, 1979; Anderson et al. 1994), and demonstrated via simulations by Berggren et al. (2007) for the CJS model using the same type of data analyzed here. Thus, point estimates of performance measures will be unaffected by heterogeneous parameters caused by pooling. Although heterogeneous parameters do not bias point estimates, they result in model-based variance estimators that will be smaller than the true variances (Anderson et al. 1994; Lebreton et al. 1992). Lack of independence among detection events will similarly produce unbiased point estimates but underestimated variances. Buchanan and Skalski (2007) used the ROSTER model to analyze the 2000 release group of hatchery summer Chinook salmon that was included in this report; using modifications of common goodness-of-fit tests (Test 2 and Test 3 from Burnham et al. 1987), they found acceptable model fit, based on guidelines in Burnham and Anderson (2002). Thus, we are not overly concerned with effects of heterogeneous parameters caused by pooling or lack of independence on results from the ROSTER model for these data.

Another way in which survival assumptions may be violated is if passing a dam via the bypass system (equivalently, being detected) affects future survival. There is evidence both for and against this hypothesis. Several researchers have found that smolts that pass one or more dams through the juvenile bypass system (JBS) have lower SAR than smolts that pass all dams undetected (e.g., Sandford and Smith 2002; Smith et al. 2006). Additionally, the same researchers found an apparent inverse relationship between the number of times a smolt is bypassed past a dam and SAR, so that the more dams a smolt passes by the JBS, the lower its SAR. Some researchers (e.g., Bouwes et al. 1999) concluded that passing a dam by the bypass system has a negative effect on survival, in contradiction to the CJS assumptions. On the other hand, Muir et al. (2001) found no significant effect of upstream detection (bypass) on downstream juvenile survival and detection for migrating yearling Chinook salmon and steelhead from 1993 through 1998. Also, Smith et al. (1998) found no significant effect on downstream juvenile survival and detection of delayed migration caused by passing a dam through the bypass system. It is conceivable that survival effects of dam bypass, if they exist, are experienced outside the hydrosystem (e.g., in the estuary or ocean), which was outside the scope of the two studies mentioned. Heterogeneous ocean and adult survival parameters would result in unbiased survival estimates with negatively biased standard errors, as described above. An alternative explanation for the pattern of SAR with number of dams bypassed is suggested by the work of Zabel et al. (2005), who found an inverse relationship between smolt size and PIT-tag detection probability at detection dams. These authors suggest that smaller smolts are more likely to enter smolt bypass systems than larger smolts. If this is the case, and if larger smolts have higher survival, then the result would be the observed relationship between number of dams bypassed and SAR: smaller smolts are both more likely to be bypassed (i.e., detected) at a detection dam, and inherently less likely to return to Lower Granite as adults, resulting in lower SAR for smolts that were bypassed more often. The two hypotheses explaining the observed pattern between dams bypassed and SAR are not necessarily mutually exclusive, but they have different implications.

If detection is size-related, then the resulting heterogeneous detection probabilities will result in unbiased survival estimates, as described above. On the other hand, if detection affects subsequent survival, then the effect on mark-recapture studies is complicated. Simulations performed for the

Comparative Survival Study (CSS; Berggren et al. 2007) suggest that inriver survival estimates will be slightly negatively biased, except for survival from release to Lower Granite, and survival over the last juvenile reach (e.g., from John Day to Bonneville), which would be slightly positively biased. However, if detection affects survival only outside the hydrosystem (e.g., in the ocean), then estimates of juvenile inriver survival should be unaffected, although estimates of the ocean return probability and SAR will be negatively biased. In this case, estimates of transportation effects (T/I and D) should be unbiased.

The assumption of common transportation probabilities for all fish in the tagged release group is violated if smolts that were previously detected and returned to the river are transported upon subsequent detection in different proportions than smolts that were previously undetected, as is often the case. This type of assumption violation has no effect on estimates of survival, detection, or transportation effect parameters because these parameters are all uncorrelated with the transportation probability parameters. Estimates of the transportation probabilities will be weighted averages of the actual transportation probabilities experienced by the release group. Assumption (A6) is necessary to separate mortality from tag loss, and to make inference from estimates based on the tagging data to the untagged population of fish. This assumption is discussed in detail in Chapter 5. Goodness-of-fit is discussed in Section 2.2.5.

2.2.2 Model Selection

The release-recapture model used in Program ROSTER is flexible in the extent to which it incorporates effects of juvenile transportation. The simplest version of the model assumes that transportation affects only juvenile survival and ocean return probabilities, but not the adult migration. In this version of the model, transportation effects end at the first adult detection site, typically Bonneville Dam. Alternatively, it has been hypothesized that adults that were transported as smolts have higher straying rates than adults that migrated wholly inriver as smolts (e.g., Chapman et al. 1997). This would result in the perceived adult upriver survival of transported fish being smaller than that of nontransported smolts. The ROSTER model can incorporate this possibility by allowing transportation effects to extend upriver past the first adult site, up to the final adult site.

The flexibility of the model to incorporate different transportation effects requires model selection to determine the optimum model, dictated by the data. In general, models that differ only in the extent of the transportation effects are nested, which means that likelihood ratio tests (LRT; Casella and Berger 1990) can be used to select between two models. In cases where candidate models are not nested, Akaike's Information Criterion (AIC; Burnham and Anderson 2002) was used to select the best model.

In cases where either LRT or AIC indicated that juvenile transportation affects the adult upriver migration, we performed further model selection to identify the adult parameters exhibiting transportation effects, again using either LRT or AIC as appropriate. Transportation effects may be exhibited in survival, detection, or censoring parameters, and in any or all adult age classes.

2.2.3 Performance Measures

We report estimates of various performance measures describing the juvenile, ocean, and adult stages of the migratory life history, as well as the effect of smolt transportation on adult returns. The effects of transportation on adult returns are analyzed for every "transport dam," that is, for every dam where at least 5,000 smolts from the (tagged) release group were transported. Transportation effects for dams with fewer tagged smolts transported were not estimated, and so are not included in any performance measure.

In general, inference from the estimated performance measures is to the tagged release group. Because it is possible that PIT-tagging affects survival (e.g., Williams et al. 2005), inference from survival estimates based on tagging data to the untagged population-at-large may be unwarranted. However, inference from the ratio of survival estimates (e.g., T/I or D estimates; see below) to the untagged population may be acceptable if survival effects of PIT tags cancel in the ratio.

Despite the caveat on possible tag effects on survival, the "systemwide" performance measures, which incorporate transportation effects from all transport dams, are estimated with both a "tagged" version and an "untagged" version. The distinction between the "tagged" and "untagged" estimators is that the "tagged" estimator depends on estimates of transportation probabilities for the (tagged) release group, while the "untagged" estimator uses assumed transportation probabilities for untagged fish. The transportation probability for a dam is the probability of being transported from that dam, conditional on being detected there (and not removed by entering the sampling room). In general, the transportation probability for tagged fish is less than 100%, because some portion of tagged fish are purposely returned to the river upon detection at the transport dams for study purposes. Untagged fish, on other hand, are generally transported from the first transport dam where they enter the juvenile bypass system, so transportation probabilities for untagged fish are assumed to be 100%. Thus, any performance measure that depends on transportation probabilities (i.e., SAR, systemwide T/I, and systemwide D; see below for descriptions) will be inherently different for tagged and untagged fish because of differential transportation probabilities for the two groups, aside from any survival effect of the PIT tag.

For example, the smolt-to-adult return ratio, SAR, is the probability of returning to Lower Granite as an adult, conditional on reaching Lower Granite as a juvenile for the entire release group (both transported and nontransported fish). The SAR includes transportation probabilities and transportation effects at each dam, and thus may be estimated using estimated transportation probabilities for tagged fish (yielding the "tagged SAR" estimator, SAR) or using assumed transportation probabilities (100%) for untagged fish (yielding the "untagged SAR" estimator, SAR^U). Note the distinction in notation: SAR (non-italicized) represents the conceptual smolt-to-adult return ratio, SAR (italicized) is the "tagged" estimator of SAR, and SAR^U is the "untagged" estimator of SAR. Because of the possibility of tag effects, the inference from the untagged SAR estimator (SAR^U) is to the (tagged) release group, had those fish been treated as transported at the transport dams, that is, had they been transported at 100% from the juvenile bypass system. In this sense, the untagged estimator SAR^U estimates the expected SAR of the release group under maximal transportation at the analyzed transport dams, while the tagged estimator SAR estimates the SAR of the release group under the transportation system as actually experienced by that release group. Similar interpretations hold for the "tagged" and "untagged" estimators of the systemwide T/I ratio ("tagged" is R_{SYS}, "untagged" is R^U_{SYS}) and of the systemwide D measure ("tagged" is D_{SYS}, "untagged" is D^U_{SYS}), described below.

Measures that involve the adult migration (i.e., SAR, ocean return probability, adult upriver survival, T/I and D) are estimated without jacks (i.e., without the age-1-ocean age class) for spring and summer Chinook salmon, and are estimated with the age-1-ocean age class for steelhead. All estimates of performance measures, including additional estimates that include jacks for spring and summer Chinook, are reported online at `http://www.cbr.washington.edu/trends/index.php`.

In addition to SAR (described above), the various components of SAR are estimated, including juvenile inriver survival, the ocean return probability, adult upriver survival, and transportation effects. Juvenile inriver survival, S_J, is the survival of nontransported smolts from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam. In most cases, this quantity is estimated directly from PIT-tag detection data from the juvenile bypass systems and adult fish ladders at the detection dams. In some cases, however, it was not possible to include Bonneville as a juvenile detection site because of low detection numbers there. In these cases, we extrapolated the estimate of survival from Lower Granite to the final juvenile detection site (either McNary Dam or John Day Dam) to estimate survival to Bonneville. We performed the extrapolation on either a per-RKM, per-detection site, or per-project basis, depending on the goodness-of-fit of the selected method's predicted reach survivals compared with the estimated reach survivals for those reaches with available survival estimates. The extrapolation is performed outside the ROSTER model. More details are provided in Appendix E.1.1.

The ocean return probability is the probability of returning from Bonneville as a smolt to Bonneville as an adult. The ocean return probability includes the age-1-ocean fish for steelhead, but not for Chinook salmon. Ocean return probability is estimated separately for nontransported fish (O_{NT}) and for dam-i transport fish (O_i; $i = LGR$ or $i = LGS$), using the assumption of 98% survival of transported smolts during transport. These measures are minimum estimates of ocean survival, because they reflect juvenile mortality between Bonneville Dam and the ocean, and adult mortality between the ocean and Bonneville. For a given species, run, and release area, the set of estimates of O_{NT} from all release years is compared to the estimates of O_i using a one-sided paired t-test, testing whether the ocean return probability for transported fish is lower than for nontransported fish at the 10% significance level. In cases where the final juvenile detection site is upstream of Bonneville Dam, the extrapolated estimate of juvenile inriver survival, $\widehat{S_J}$, may be used to adjust the estimate of the ocean return probability so that it does not include juvenile mortality upstream of Bonneville; more details are provided in Appendix E.1.2. This was unnecessary for the release groups analyzed here. In cases where the first and only adult detection site is Lower Granite Dam (i.e., for release years 1996-1999), it is not possible to separate the ocean return probability and adult upriver survival; O_{NT} and O_i are not reported in these cases. Additionally, it was impossible to separate the ocean return probability and adult upriver survival in cases where sparse adult data precluded using the full ROSTER model to fit the release-recapture data.

Perceived adult upriver survival, S_A, is the probability of reaching Lower Granite Dam (as an adult), conditional on reaching Bonneville Dam as an adult. This measure is labeled "perceived" adult survival because its complement, $1-S_A$, includes natural mortality, fishing mortality, straying between Bonneville and Lower Granite, and fallback that is not followed by reascension. Thus, S_A is a minimum estimate of true adult upriver survival, and is analogous to the adult conversion rate. Often, the qualifier "perceived" is assumed to be understood, and will be omitted. The estimator of adult upriver survival incorporates the proportions of smolts transported, transportation effects, and the age-specific perceived adult upriver survival probabilities. Because Lower Granite is the final detection site, it is not possible to separately estimate survival to Lower Granite and the detection probability there. Thus, if the detection probability at Lower Granite is 100% (often considered to be the case), then S_A is an unbiased measure of perceived adult upriver survival for the release group. On the other hand, if the detection probability at Lower Granite is < 100%, then S_A is a minimum value of perceived adult upriver survival.

Several different measures of S_A are reported. The first, $S_{A_{Release}}$ (abbreviated $S_{A_{Rel}}$), is the average perceived adult upriver survival for all fish in a given release group. This measure incorporates the proportions of fish returning in the different ocean age classes, and includes data from several return years. The $S_{A_{Rel}}$ measure includes age-1-ocean returns for steelhead, but not for Chinook salmon. Another measure, $S_{A_{Return}}$ (abbreviated $S_{A_{Ret}}$), is the average perceived adult upriver survival for all tagged fish known to be present in the river in a given return year. This measure incorporates adult data from several release groups, but only from a single return year. Both $S_{A_{Rel}}$ and $S_{A_{Ret}}$ include both transported and nontransported fish.

The two basic measures of adult upriver survival ($S_{A_{Rel}}$ and $S_{A_{Ret}}$) are both estimated because they are useful for different purposes. Adult upriver survival by release group, $S_{A_{Rel}}$, is a component of SAR for a given release group, and is helpful in determining the relative contributions of the different migratory stages to overall mortality (see Section 2.2.4). Additionally, $S_{A_{Rel}}$ is useful for relating adult upriver survival to juvenile migration experience, such as transportation. Adult upriver survival by return group, $S_{A_{Ret}}$, is useful for assessing the effects of annual management strategies and operations directly on migrating adults. It gives a snapshot of the state of the river in a given calendar year. The two measures $S_{A_{Rel}}$ and $S_{A_{Ret}}$ are complementary, providing assessments of adult migratory survival through the hydrosystem from two different management viewpoints.

The measure $S_{A_{Rel}}$ incorporates adult detection data from both nontransported and transported fish. This measure may also be estimated separately for nontransported and transported fish, in cases where smolt transportation occurred. The measure $S_{A_{NT}}$ is the perceived adult upriver survival by release group for nontransported fish, and the measure S_{A_i} is the perceived adult upriver survival by release group for dam-i transport fish ($i = LGR$ or $i = LGS$). For a given species, run, and release area, the annual estimates of $S_{A_{NT}}$ and the S_{A_i} are compared using a one-sided paired t-test, testing whether adult upriver survival for transported fish is lower than for nontransported fish at the 10% significance level. The measure S_{A_i} cannot be estimated for transport groups from dam i if those transport groups were censored because of low numbers. Thus, estimates of S_{A_i} are not available for all dams with any transportation in all years.

Transportation effects are characterized in several ways. Generally, the transport-inriver ratio (T/I) is the ratio of the survival probability to Lower Granite for transported fish relative to that of nontransported fish. This measure is reported both for specific dams from which juveniles were transported, and as a systemwide measure. Estimators of the T/I ratio are denoted by R (with suitable subscripts; see below), following the notation of Sandford and Smith (2002). The dam-specific measures (R_{LGR} and R_{LGS}) reflect only the effect of transportation from the dam in question, unconfounded by the effect of any transportation from downstream dams. Each dam-specific measure is the ratio of the smolt-to-adult return probability from the transport dam to Lower Granite Dam for transported fish relative to that of nontransported fish. Because the dam-specific T/I measures are conditional on fish transported from the dam in question and do not depend on the transportation probability at any dam, a separate "untagged" estimator is unnecessary. The systemwide T/I (tagged R_{SYS} or untagged R^U_{SYS}) gives the relative effect of the transportation system on the smolt-to-adult return ratio of the entire release group, including the nontransported fish. It reflects effects on survival of transportation from all dams, as well as the proportion of fish transported (which differs between R_{SYS} and R^U_{SYS}) and the survival of nontransported fish. The systemwide T/I is the ratio of the smolt-to-adult return ratio from Lower Granite to Lower Granite under the transportation system as it was experienced by the release group, relative to the expected smolt-to-adult return ratio had there been bypass operations but no transportation operations (i.e., all fish migrated past dams inriver). The smolt-to-adult return ratios used in estimating the systemwide T/I and the dam-specific T/I measures were estimated without the age-1-ocean returns for spring and summer Chinook salmon. One-sided z-tests were used to test whether annual values of T/I were greater than 1 at the 10% significance level, using the test statistic

$$z = \frac{\ln\left(\widehat{R}\right)}{\widehat{SE}\left(\widehat{R}\right)\Big/\widehat{R}}, \tag{2.1}$$

where $\widehat{R}$ is the MLE of R_{SYS}, R_{LGR}, or R_{LGS}, as appropriate. Under the null hypothesis H_0 : $R \leq 1.0$, z follows an approximate standard normal distribution.

We report estimates of differential post-Bonneville mortality (D), the ratio of post-Bonneville survival (to Lower Granite Dam as adults) of transported fish relative to that of nontransported fish. As with the T/I measures, D is reported both as a systemwide measure (tagged D_{SYS}, and untagged D^U_{SYS}) and as a series of measures specific to the transport dams (D_{LGR} and D_{LGS}). The systemwide measure incorporates all transport dams and the proportions of fish that are transported at those dams, which differ between D_{SYS} and D^U_{SYS}. Each dam-specific measure focuses on a single transport dam. Each measure of D depends on the survival of transported fish during transport, and inriver survival of nontransported smolts. Additionally, each D measure also depends on the ocean return probability and adult upriver survival of nontransported fish, and multiplicative effects of transportation on the ocean return probability and adult upriver survival (i.e., the dam-specific T/I ratio) for each transport dam. We assumed 98% survival of transported fish during transport. In cases where the final juvenile detection site is upstream of Bonneville Dam, both the systemwide and dam-specific measures of D incorporate an expansion factor to account for inriver juvenile survival between the final juvenile detection site and Bonneville (Appendix E.4). Estimates of D were unavailable for release groups for which estimates of juvenile inriver survival were not available.

Interpretation of estimates of D measures has been contentious. Generally, if $D = 1$, then both nontransported and transported fish had the same survival in the estuary and ocean and as adults, indicating that the method of juvenile migration (transport or inriver) did not affect survival after exiting the hydrosystem. Because survival of transported smolts during transportation (i.e., on the barge) is nearly 100% (assumed = 98%), comparing the systemwide D to juvenile inriver survival is equivalent to comparing the SAR (from Lower Granite back to Lower Granite) of transported fish to that of nontransported fish. In other words, if D is greater than juvenile inriver survival, then the T/I is greater than 1 and transportation resulted in higher SAR. If D is less than juvenile inriver survival, then the T/I is less than 1, and transportation resulted in lower SAR for transported fish. If D is less than 1 but greater than inriver survival, then the T/I is greater than 1, but not as high as expected if there had been no differential mortality of transported fish after passing Bonneville, relative to nontransported fish. Differential post-Bonneville mortality of transported fish relative to nontransported fish may occur for several alternative reasons which are not mutually exclusive: (1) natural culling of transport fish that would have occurred in the hydrosystem had they not been transported; (2) effects of differential timing of estuary entry (transport fish reach the estuary sooner than nontransport fish); (3) a size-related survival difference that may exist if transported fish are inherently smaller than nontransported fish (based on a possible size-selectivity of the detection system), or vice versa; and (4) delayed effects of transportation stress. Values of D less than 1 do not indicate that transportation is harmful overall, but rather that SAR could have been yet better for transported fish. If D is less than 1 but greater than juvenile inriver survival, then despite lower survival of transported fish after release from the barge, transported fish still returned to Lower Granite in higher proportions than nontransported fish, so the net effect of transportation is still positive. On the other hand, values of D less than the juvenile inriver survival, or equivalently values of T/I less than 1, indicate an overall negative effect of transportation on adult return rates. Because we already compare estimates of T/I to 1, further comparisons of D to juvenile inriver survival would be redundant. Instead, we compare estimates of D to 1. One-sided z-tests were used to test whether annual values of D were greater than 1.0 at the 10% significance level, using the test statistic

$$z = \frac{\ln\left(\widehat{D}\right)}{\widehat{SE}\left(\widehat{D}\right)/\widehat{D}}, \tag{2.2}$$

where $\widehat{D}$ is the MLE of D_{SYS}, D_{LGR}, or D_{LGS}, as appropriate. Under the null hypothesis $H_0 : D \leq 1.0$, z follows an approximate standard normal distribution.

Both T/I and D are ratios of a survival probability of transported fish to that of nontransported fish. The estimators used here use all transported fish in the transport group, including those detected upstream of their transport dam, and all nontransported fish in the nontransport ("control") group, including those that were undetected, singly-detected, or multiply-detected at the transport dams or elsewhere as juveniles. Because the ROSTER model assumes that detection has no effect on subsequent survival, no distinction is made between detected and nondetected juveniles, except for the fact that nondetected smolts were also nontransported (by default) and that transported smolts were detected (also by default). Thus, estimation of transportation effects on adult returns to Lower Granite use all fish in the release group, without restrictions to undetected fish. Similarly, estimation of the ocean return probability and adult upriver survival of nontransported fish for estimates of D is based on the estimated proportion of the release group that reached Bonneville without being transported, though with the possibility of being detected.

For both T/I and D, we performed a meta-analysis testing whether the T/I or D estimates tended to be greater than 1 on average, using results of the individual one-sided z-tests from Equations (2.1) and (2.2) (Woodroofe 1975). For a given performance measure (e.g., R_{SYS}), species, run, and release area, let P_i be the P-value for the z-test for release year i. Then the overall significance test is based on the chi-square statistic

$$\widetilde{\chi^2}_{2k} = -2\sum_{i=1}^{k} \ln P_i, \tag{2.3}$$

where k is the number of release years with estimates. Under the null hypothesis (H_0 : T/I ≥ 1 or $H_0 : D \geq 1$), the statistic $\widetilde{\chi^2}_{2k}$ follows a χ^2 distribution with $2k$ degrees of freedom, and the overall P-value from the meta-analysis is calculated as

$$P = \Pr\left[\chi^2_{2k} \geq \widetilde{\chi^2}_{2k}\right]. \tag{2.4}$$

The data from some release groups were too sparse to allow for full analysis using the ROSTER model. This happened when very low detection numbers at the final juvenile dam were followed by low ocean survival of nontransported fish. Low detection numbers at the final juvenile dam may occur because of high transportation probabilities at upstream dams, small release sizes, or inherently low detection probability caused by equipment and operations. Years with high smolt mortality in the lower reaches may result in sparse data of this sort, with nontransported fish returning as adults in very low numbers but transport fish returning in relatively high numbers. Few juvenile detections followed by low ocean survival can produce estimates of juvenile inriver survival over the final juvenile reach that are considerably greater than 1 (e.g., > 1.5). In some cases, this problem may be avoided by removing the final juvenile dam (i.e., Bonneville) from the juvenile detection sites, using juvenile detections only through either McNary or John Day, and extrapolating the estimated juvenile inriver survival parameter (S_J) to include the reach to Bonneville; see the discussion of S_J above, and Appendix E.1.1. In other cases, however, all downstream dams had few juvenile detections of fish that were subsequently detected as adults. The part of the statistical model that is related to juvenile inriver survival in the lower reaches and ocean survival is not robust to sparse data of this sort, and thus it was necessary to devise an alternative analysis method for these cases of sparse data.

Although the ROSTER model is not appropriate for full analysis of release years with sparse juvenile detections and low return rates from the ocean of nontransported fish, it can be partially used. The part of the model related to the juvenile migration in upper river reaches (e.g., from release to Lower Granite or Little Goose) is robust to low detection rates at the lower dams combined with low ocean survival. This is because estimation of the parameters related to migration through the upper reaches is based almost entirely on juvenile detections, and is negligibly affected by low ocean survival. Thus, we can estimate juvenile survival from release to the Snake River dams with confidence, despite low ocean survival of inriver fish. We can combine estimates of juvenile survival, detection, censoring, and transportation with simple tallies of adult detections to heuristically estimate certain performance measures, such as SAR, transportation effects, and perceived adult upriver survival (Appendix E.5). However, juvenile inriver survival through the hydrosystem (S_J), the ocean return probability (O_{NT} and O_i), and D cannot be estimated from the model in these cases.

2.2.4 Proportion of Total Integrated Mortality

In general, the smolt-to-adult return ratio (SAR) is the product of survival through the different migratory life stages: juvenile (smolt), ocean, and adult. The contribution of each of the three migratory stages to the overall mortality (from passing Lower Granite as a juvenile to return to Lower Granite as an adult) can be represented in two ways. First, the proportion of the total mortalities that occurred in each migratory stage may be calculated. This approach may be misleading because the migratory stages occur in succession instead of concurrently. For example, there may be more mortalities during the juvenile migratory stage than in the adult migratory stage either because the juvenile stage has a higher mortality probability or because the juvenile stage comes first, so that there are more fish experiencing the mortality risk in that stage. Alternatively, the effect of the stage order may be removed by measuring the relative survivals on the log scale. This approach removes the confounding caused by the successive nature of the three migratory stages.

As a simplified example, consider survival through only two successive life stages, a and b. Stage a comes first, with the probability of surviving the entire stage equal to S_a. Stage b immediately follows stage a, and has a conditional survival probability of S_b, given survival through the end of stage a. The overall survival through both stages is $S = S_a S_b$. Each of the stage survivals can be written in terms of an instantaneous mortality rate and the length of the life stage as follows:

$$S_a = \exp(-r_a t_a) \qquad\qquad S_b = \exp(-r_b t_b);$$

equivalently,

$$-\ln S_a = r_a t_a \qquad\qquad -\ln S_b = r_b t_b,$$

where r_a is the instantaneous mortality rate during life stage a, t_a is the time spent in life stage a, and r_b and t_b are defined analogously. The higher the mortality risk in life stage a, the larger r_a will be, and the smaller the survival S_a will be. Alternatively, S_a may be low because the fish spent a long time in life stage a, even if the instantaneous mortality rate r_a is low. With variable amounts of time spent in the different life stages, it is not possible to separate r_a and t_a. Nevertheless, their product ($-\ln S_a = r_a t_a$) is a useful measure of the overall risk of mortality during the life stage.

The overall survival through the two life stages is $S = S_a S_b$. On the log scale, this overall survival is expressed in terms of the stage-specific mortality rates and times spent in each stage:

$$-\ln S = r_a t_a + r_b t_b.$$

The measure $-\ln S$ integrates the stage-specific instantaneous mortality rates (r_a, r_b) over the times spent in the two life stages (t_a, t_b). In this sense, $-\ln S$ is the "total integrated mortality" through the two life stages. By comparing $-\ln S_a$ and $-\ln S_b$ to $-\ln S$, it is possible to identify the contributions of the individual stages to the total integrated mortality, without confounding by the order of the stages. This comparison on the log scale treats the stages as if they occurred concurrently. Define μ_a as $\mu_a = -\ln S_a / -\ln S$. The fraction μ_a is the proportion of total integrated mortality that is accounted for by stage a. The measure μ_b is defined analogously.

For example, consider the case (Case 1) where S_a=S_b=0.4 (Table 2.2). With common survival probabilities in the two stages, it is intuitively reasonable to expect that the two stages contribute equally to overall survival. The overall survival through both stages is $S = 0.16$. Out of 100 fish present at the beginning of the first stage, 40 will survival stage a and 60 will die during that stage.

Of the 40 that are present at the beginning of the second stage, 40% or 16 will survive through stage b, and 24 will die. Thus, stage a accounts for 60 out of 84 or approximately 71% of the actual mortalities, while stage b accounts for only 24 of 84 mortalities, or 29%. Although both stages have the same conditional survival probability (0.4), the first stage has more mortalities than the second (60 versus 24) because there are more fish available to die in the first stage. However, it is apparent from the fact that $S_a = S_b$ that the two stages contribute equally to the overall survival. This is reflected by the μ_a and μ_b measures, which represent the proportion of total integrated mortality. In this case, $\mu_a = \mu_b = \frac{\ln 0.4}{2 \ln 0.4} = 1/2$ (Table 2.2, Case 1). Because $S_a = S_b$, we have $\mu_a = \mu_b$.

Next, consider the case where survival in the first stage is high ($S_a = 0.8$) and survival in the second stage is low ($S_b = 0.3$; Case 2, Table 2.2). The overall survival through the two stages is $S = 0.8 \times 0.3 = 0.24$. With 100 individuals present at the beginning of stage a, 20 will die during stage a and 80 will survive to stage b. Of the 80 that survive to stage b, 56 will die during stage b and 24 will survive to the end of the stage. Overall, 76 individuals will die during the two stages, with 26% of the mortalities occurring during stage a and 74% occurring in stage b. Now consider the reverse case (Case 3, Table 2.2), where survival is low in the first stage but high in the second stage: $S_a = 0.3$ and $S_b = 0.8$. As in Case 2, the overall survival is $S = 0.3 \times 0.8 = 0.24$. Of 100 individuals present at the beginning of stage a, 70 die during stage a and 30 survive to stage b. Of these 30, 6 die during stage b and 24 survive. Although the overall survival probability is the same as in Case 2 ($S = 0.24$), the proportion of the total mortalities occurring in each stage is different. In the earlier example, the stage with the high (80%) survival probability accounted for 26% of the mortalities, while the stage with the low (30%) survival accounted for 74% of the mortalities. In this example where the low survival stage occurs first, the low (30%) survival stage accounts for 92% of the mortalities, while the high (80%) survival stage accounts for 8% of the mortalities. Thus, the order in which the high and low survivals occur affects the proportion of the mortalities they account for. A high proportion of the total number of mortalities may occur in a given stage either because that stage has low survival or because that stage occurs first.

Assessing stages in terms of their relative contributions to the total integrated mortality removes the effect of stage order. In Case 2, the proportion of total integrated mortality accounted for by stage a is $\mu_a = -\ln(0.8)/-\ln(0.24) = 16\%$, and the proportion of total integrated mortality accounted for by stage b is $\mu_b = -\ln(0.3)/-\ln(0.24) = 84\%$ (Table 2.2, Case 2). In Case 3, the high-survival stage is stage b, and the proportion of total integrated mortality for stage b is $\mu_b = 16\%$. The low-survival stage is stage a, with $\mu_a = 84\%$ (Table 2.2, Case 3). Thus, the order of the high-survival and low-survival stages is not confounded with the relative survivals in the measures of the components of total integrated mortality: the stage with 80% survival accounts for 16% of the total integrated mortality, regardless of whether it comes before or after the stage with 30% survival. Thus, examining the components of the total integrated mortality focuses attention on the relative mortality risks without their being confounded with the order of the life stages.

Table 2.2: Components of mortality measures for two-stage example. The number that survive and the number that die refer to the survivals and mortalities during each life stage, out of N=100 individuals present at the beginning of stage a. Survival probabilities (S_i) are multiplied to produce the survival total, and other values are added to produce their respective totals.

		Parameters			**N=100 at start of stage a**		
Case	**Life Stage (i)**	**Survival Probability S_i**	$-\ln S_i$	**Proportion of Total Integrated Mortality (μ_i)**	**Number Survive**	**Number Die**	**Proportion of Total Mortalities**
1	a	0.4	0.92	50%	40	60	71.4%
	b	0.4	0.92	50%	16	24	28.6%
	Total	0.16	1.83	100%		84	100%
2	a	0.8	0.22	15.6%	80	20	26.3%
	b	0.3	1.20	84.4%	24	56	73.7%
	Total	0.24	1.43	100%		76	100%
3	a	0.3	1.20	84.4%	30	70	92.1%
	b	0.8	0.22	15.6%	24	6	7.9%
	Total	0.24	1.43	100%		76	100%

The cases in Table 2.2 relate to survival and mortality in two successive life stages. The migratory portion of the salmon life history analyzed in this report has three stages: the juvenile inriver migration, ocean life stage, and adult upriver migration. The same approach can be used to assess the contribution of each life stage to the total mortality of nontransported fish during the migration between passing Lower Granite as a smolt and returning to Lower Granite as an adult, by estimating the proportion of total integrated mortality of each migratory stage based on estimates of survival of nontransported fish through those stages. In general, the SAR of nontransported fish (SAR_{NT}) is the product of inriver juvenile survival, ocean survival, and adult upriver: $SAR_{NT} = S_J \times O_{NT} \times S_{A_{NT}}$, where S_J is the survival of nontransported smolts from LGR to BON, O_{NT} is the ocean return probability (from BON to BON) of nontransported fish, and $S_{A_{NT}}$ is the adult upriver survival (from BON to LGR) of nontransported fish. The integrated mortality of the juvenile inriver migration from Lower Granite to Bonneville is $-\ln S_J$, the product of the instantaneous mortality rate during the juvenile inriver migration and the length of time spent migrating from LGR to BON. Similarly, the integrated mortality of the ocean life stage is $-\ln O_{NT}$, and the integrated mortality of the adult life stage is $-\ln S_{A_{NT}}$. The total integrated mortality during the migration between passing LGR as a smolt and returning to LGR as an adult is $-\ln SAR_{NT}$, which is also equal to $-(\ln S_J + \ln O_{NT} + \ln S_{A_{NT}})$. Then, the proportion of total integrated mortality accounted for by the juvenile inriver migration is $\mu_J = -\ln S_J / -\ln SAR_{NT}$, the proportion of total integrated mortality accounted for by the ocean life stage is $\mu_O = -\ln O_{NT} / -\ln SAR_{NT}$, and the proportion of total integrated mortality accounted for by the adult upriver migration is $\mu_A = -\ln S_{A_{NT}} / -\ln SAR_{NT}$. The measures μ_J, μ_O, and μ_A represent the components of total integrated mortality accounted for by each migratory stage, unconfounded by the order in the stages occur. Estimates of μ_J, μ_O, and μ_A are reported graphically for each release group for which estimates of ocean and adult upriver survival are available. Two examples are discussed below.

Example 1 Consider a simple hypothetical scenario where each migratory stage has the same overall survival probability of 0.5: $S_J = O_{NT} = S_{A_{NT}} = 0.5$ (Table 2.3). In this case, the integrated mortality during the juvenile inriver migration is $-\ln(0.5) = 0.69$. Because the ocean and adult migrations have the same survival probability, they have the same integrated mortality: $-\ln O_{NT} = -\ln S_{A_{NT}} = 0.693$. The total integrated mortality during the LGR-to-LGR migration is $-(\ln S_J + \ln O_{NT} + \ln S_{A_{NT}}) = 2.079$. The proportion of total integrated mortality that occurred during the juvenile inriver migration is $\mu_J = 0.693/2.079 = 0.33$ or 1/3. Likewise, the proportion of total integrated mortality that occurred during the ocean life stage is also 1/3, and the proportion of total integrated mortality that occurred during the adult upriver migration is also 1/3. Because the three life stages have common survival probabilities, their individual contributions to the total integrated mortality are equal.

The proportion of total integrated mortality due to a particular life stage should not be confused with the proportion of the total counted mortalities that occurred during that life stage. Continuing Example 1, consider the mortalities occurring in each migratory stage if $N = 10,000$ smolts reached

LGR with no possibility of being transported at LGR or downstream (Table 2.3). Juvenile inriver survival (S_J) of 0.5 means that $0.5 \times 10,000 = 5,000$ nontransported smolts will reach Bonneville, and 5,000 nontransported smolts will die between LGR and Bonneville. The ocean return probability of $O_{NT} = 0.5$ means that of the 5,000 smolts that reached Bonneville, $0.5 \times 5,000 = 2,500$ nontransported fish will return to Bonneville as an adult, and 2,500 fish will die between reaching Bonneville as a juvenile and returning there as an adult. The adult survival of $S_{A_{NT}} = 0.5$ means that of the 2,500 nontransported adults that return to Bonneville, $0.5 \times 2,500 = 1,250$ will reach LGR and 1,250 will die between Bonneville or LGR. The adult "deaths" may include both harvest and straying to non-natal tributaries downstream of LGR. The total number of mortalities is 5,000 + 2,500 + 1,250 = 8,750, with 57.1% of the deaths occurring during the juvenile inriver migration, 28.6% occurring during the ocean life stage, and 14.3% of the deaths occurring during the adult upriver migration. Thus, although the majority of the mortalities occurred during the juvenile migration because more fish were alive at the start of that life stage, the three life stages contribute equally to the total integrated mortality. This would be true regardless of the survival probability in each life stage, as long as the three life stages had equal survival probabilities (i.e., $S_J = O_{NT} = S_{A_{NT}}$).

Example 2 Example 1 dealt with the simple and unlikely situation in which the three life stages have common overall survival probabilities. Here we consider a more realistic example, where the ocean return probability is much lower than juvenile inriver survival or adult upriver survival. For Example 2, let $S_J = 0.5$ as before, but now assume that $O_{NT} = 0.02$ and $S_{A_{NT}} = 0.9$ (Table 2.4). In this case, the integrated mortality during the juvenile inriver migration is $-\ln S_J = 0.693$ as before, while the integrated mortality during the ocean life stage is $-\ln O_{NT} = 3.912$, and the instantaneous mortality rate during the adult upriver migration is $-\ln S_{A_{NT}} = 0.105$. The total integrated mortality during the migration from LGR to LGR is $-\left(\ln S_J + \ln O_{NT} + \ln S_{A_{NT}}\right) = 4.711$. The proportion of total integrated mortality that is due to the juvenile inriver migration is $\mu_J = 0.147$, the proportion of total integrated mortality due to the ocean life stage is $\mu_O = 0.830$, and the proportion of total integrated mortality due to the adult upriver migration is $\mu_A = 0.022$. In this case, the three migratory stages have very different contributions to the total integrated mortality because the survival probabilities are very different over the three life stages.

Continuing Example 2, again consider the scenario in which $N = 10,000$ smolts reach LGR without the possibility of transportation. Juvenile inriver survival of $S_J = 0.5$ means that, in expectation, 5,000 nontransported smolts will reach Bonneville and 5,000 nontransported smolts will die between LGR and Bonneville. The ocean return probability of $O_{NT} = 0.02$ means that of the 5,000 smolts that reached Bonneville, approximately $0.02 \times 5,000 = 100$ will return as non-jack adults to Bonneville, while 4,900 will die between reaching Bonneville as a smolt and returning there as an adult. The nontransport adult upriver survival probability of $S_{A_{NT}} = 0.9$ means that of the 100 smolts that reached Bonneville as an adult, approximately 90 will reach LGR and 10 will be viewed as mortalities (including harvest and straying) between Bonneville and LGR. The total number of mortalities between reaching LGR as a juvenile and returning there as an adult is approximately 9,910. A slight majority of the mortalities occurred during the inriver juvenile migration (5,000 of 9,910, or 50.5%), with an almost equal number in the ocean (4,900, or 49.4%). Only 0.1% of the total mortalities occurred during the upriver adult migration. These numbers do not agree with the proportions of the total integrated mortality (μ_J, μ_O, and μ_A) computed above, because a different number of fish are subject to mortality in the different life stages (Table 2.4). The number of fish that die in a particular migratory stage depends both on the proportion of total integrated mortality in that stage (related but unequal to the probability of mortality in that stage) and on the number of fish that enter that stage. More fish died during the juvenile inriver migration than in the ocean because more fish entered the juvenile migration than entered the ocean life stage. Assessing the relative contributions of the migratory stages to total mortality on the total integrated mortality scale, rather than on the body count scale, removes the dependence on the number of fish entering each migratory stage and the order of the stages.

Table 2.3: Components of total integrated mortality for Example 1. The number that survive and the number that die refer to the survivals and mortalities during each migratory stage, out of N=10,000 inriver (nontransported) smolts at LGR. Survival probabilities (S_i) are multiplied to produce the survival total, and other values are added to produce their respective totals.

	Parameters			**N=10,000 nontransport smolts at LGR**		
Life Stage (i)	**Survival Probability** S_i	$-\ln S_i$	**Proportion of Total Integrated Mortality (μ_i)**	**Number Survive**	**Number Die**	**Proportion of Total Mortalities**
Juvenile	0.5	0.69	33.3%	5,000	5,000	57.1%
Ocean	0.5	0.69	33.3%	2,500	2,500	28.6%
Adult	0.5	0.69	33.3%	1,250	1,250	14.3%
Total	0.125	2.08	99.9%		8,750	100.0%

Table 2.4: Components of total integrated mortality for Example 2. The number that survive and the number that die refer to the survivals and mortalities during each migratory stage, out of N=10,000 inriver (nontransported) smolts at LGR. Survival probabilities (S_i) are multiplied to produce the survival total, and other values are added to produce their respective totals.

	Parameters			**N=10,000 nontransport smolts at LGR**		
Life Stage (i)	**Survival Probability** S_i	$-\ln S_i$	**Proportion of Total Integrated Mortality (μ_i)**	**Number Survive**	**Number Die**	**Proportion of Total Mortalities**
Juvenile	0.50	0.693	14.7%	5,000	5,000	50.5%
Ocean	0.02	3.912	83.0%	100	4,900	49.4%
Adult	0.90	0.105	2.2%	90	10	0.1%
Total	0.009	4.711	99.9%		9,910	100.0%

2.2.5 Goodness-of-Fit

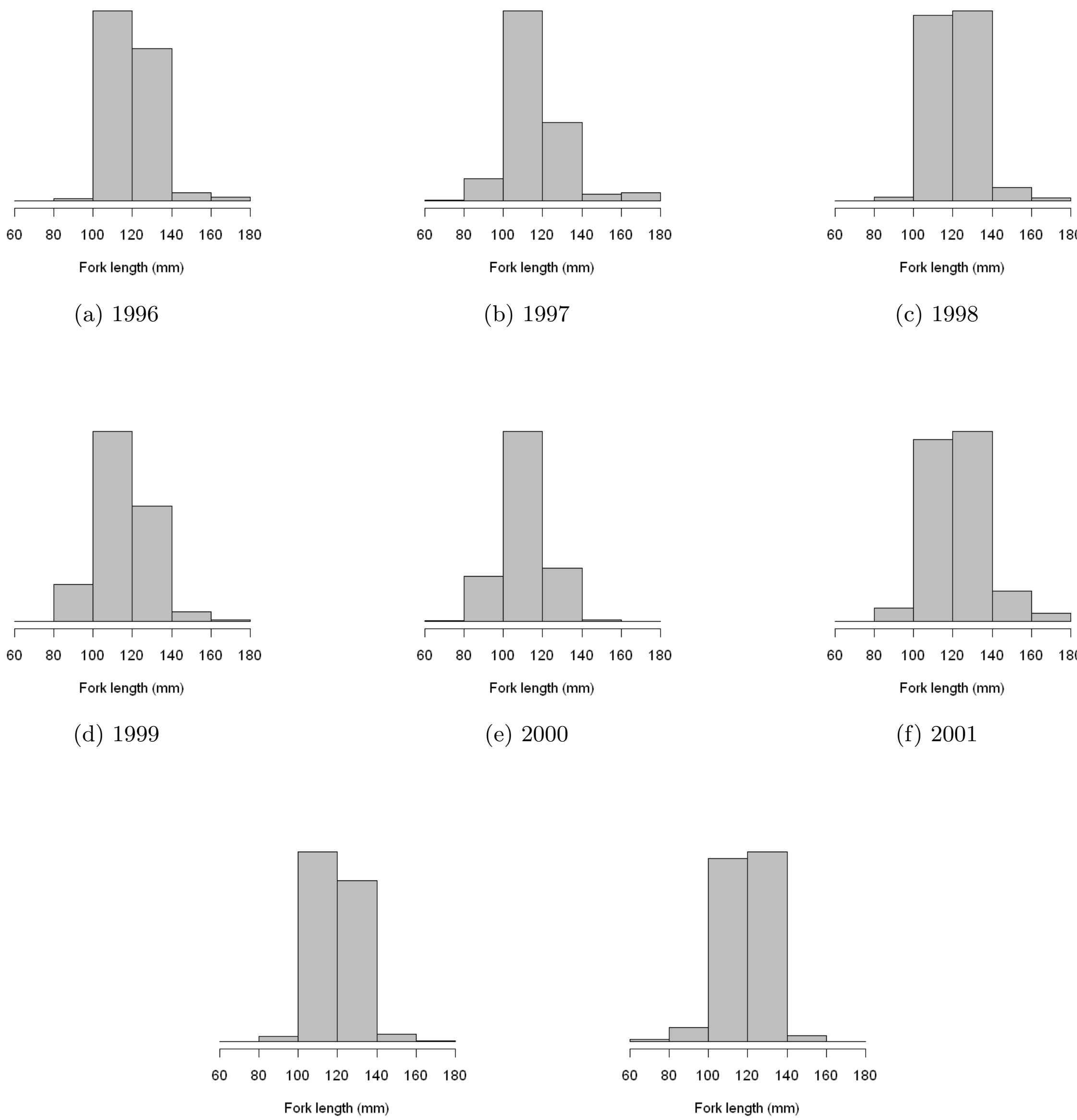
The goodness-of-fit of the ROSTER model was assessed graphically by comparing the estimated SAR (Eq. (E.14)) calculated by the ROSTER model to the heuristic SAR estimate (Eq. (E.28)), which is simply the total number of adults detected at Lower Granite divided by the number of smolts estimated to have passed Lower Granite without being removed (censored) there. No distinction is made between transported and nontransported fish when estimating the heuristic SAR.

Chapter 3

Description of PIT-Tag Release Groups Used in Analysis

The annual regional release groups are composed of multiple smaller releases (Table C.1-C.5). Three types of spring Chinook salmon releases were analyzed for each release year, categorized by release area. The smallest groups were released in the Clearwater River Basin, denoted "CLR." Larger release groups were released in the Snake River Basin, excluding the Clearwater Basin; this release area is denoted "SNK." These two groups were pooled to form a larger Snake River Basin group, including the Clearwater Basin; this combined release area is denoted "SNB." Summer Chinook salmon and steelhead release groups are both denoted "SNB."

Figures 3.1 to 3.5 show summaries of size-at-tagging (i.e., fork length at tagging) for each annual release group. Size-at-tagging information was not available for all fish, in particular for the 2003 releases. Median fork length at tagging for spring Chinook salmon from the Clearwater (release area CLR; Figure 3.1) ranged from 112 mm in 2000 to 122 mm in 2001. For spring Chinook from the Snake River Basin, excluding the Clearwater (release area SNK), median fork length at tagging ranged from 113 mm in 1997 to 125 mm in 1996 (Figure 3.2). For the pooled release groups of spring Chinook from the Snake River Basin including the Clearwater (release area SNB), the median fork length at tagging ranged from 114 mm in 1997 to 122 mm in 1996 (Figure 3.3). For summer Chinook, median fork length ranged from 114 mm in 2003 to 129 mm in 1997 and 2001 (Figure 3.4). For steelhead, median fork length at tagging ranged from 185 mm in 1996 to 202 mm in 2000 and 2002 (Figure 3.5).

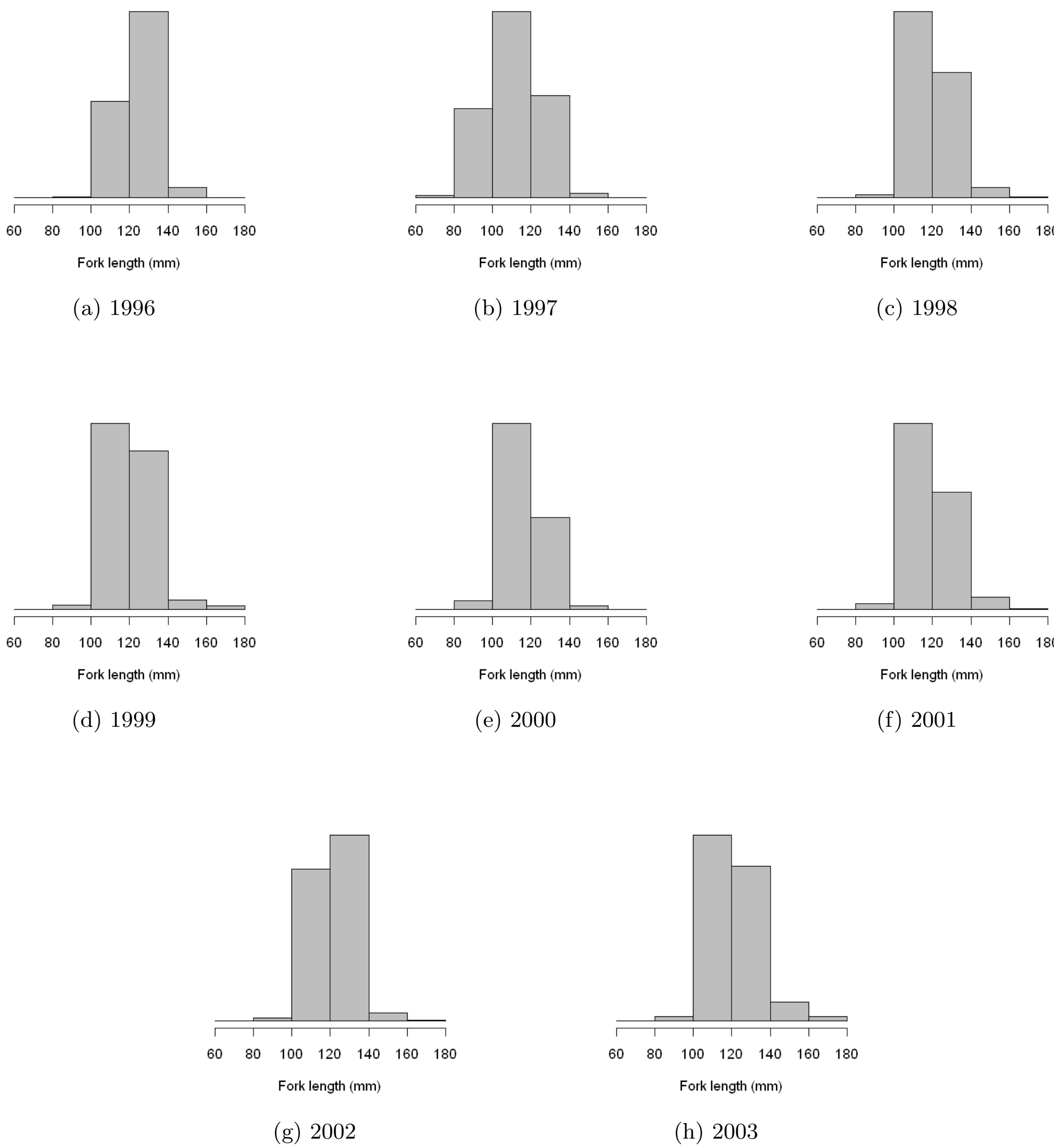


(a) 1996 (b) 1997 (c) 1998

(d) 1999 (e) 2000 (f) 2001

(g) 2002 (h) 2003

Figure 3.1: Fork length (mm) at tagging for spring Chinook salmon releases from the Clearwater (release area CLR). Size-at-tagging data were not available for all tagged fish in all years. Frequency distributions represent the following proportions of annual release groups: 1996 - 2000 (100%); 2001 - 2002 (99.9%); 2003 (17.4%).

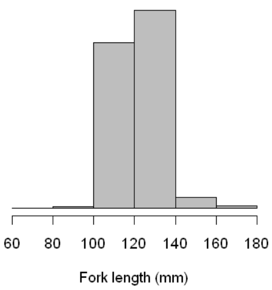


(a) 1996 (b) 1997 (c) 1998

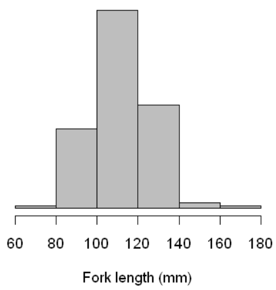
(d) 1999 (e) 2000 (f) 2001

(g) 2002 (h) 2003

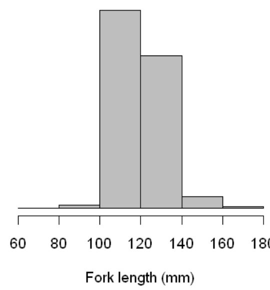
Figure 3.2: Fork length (mm) at tagging for spring Chinook salmon releases from the Snake River, excluding the Clearwater (release area SNK). Size-at-tagging data were not available for all tagged fish in all years. Frequency distributions represent the following proportions of annual release groups: 1996 (99.7%); 1997 (99.9%); 1998 (100%); 1999 (100%); 2000 (99.8%); 2001 (99.7%); 2002 (99.2%); 2003 (80.2%).



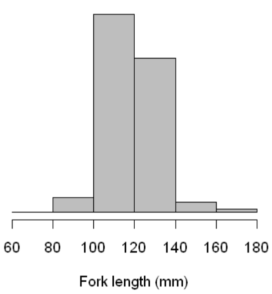
(a) 1996



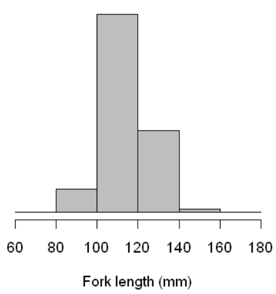
(b) 1997



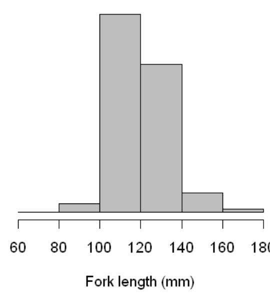
(c) 1998



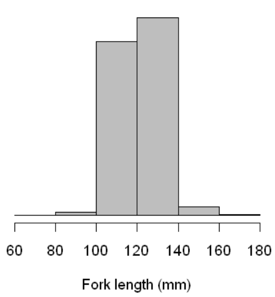
(d) 1999



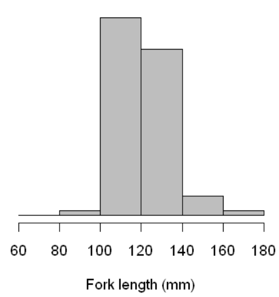
(e) 2000



(f) 2001

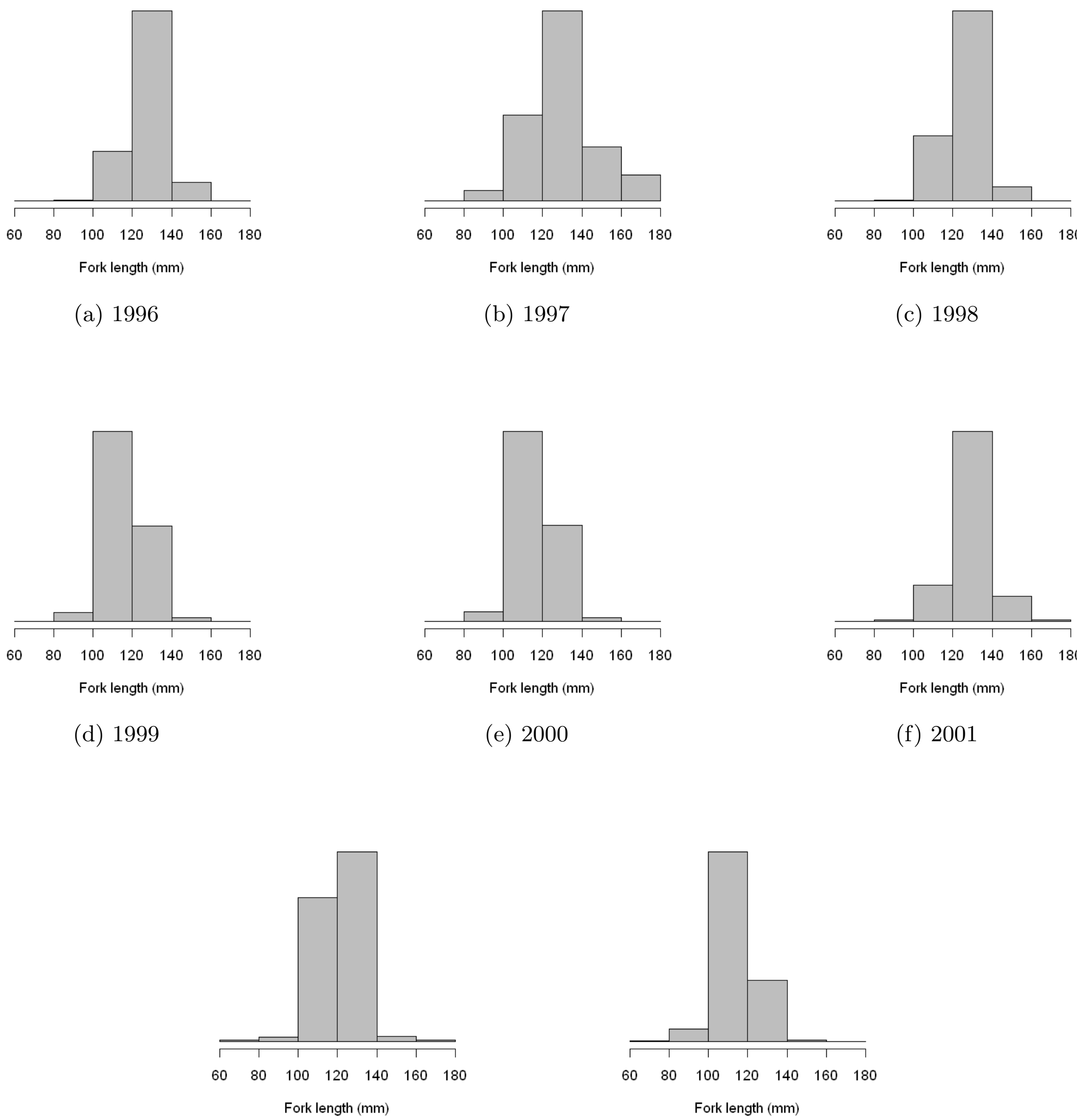


(g) 2002



(h) 2003

Figure 3.3: Fork length (mm) at tagging for spring Chinook salmon releases from the Snake River, including the Clearwater (release area SNB). Size-at-tagging data were not available for all tagged fish in all years. Frequency distributions represent the following proportions of annual release groups: 1996 (99.8%); 1997 (100%); 1998 (100%); 1999 (100%); 2000 (99.9%); 2001 (99.8%); 2002 (99.3%); 2003 (67.7%).

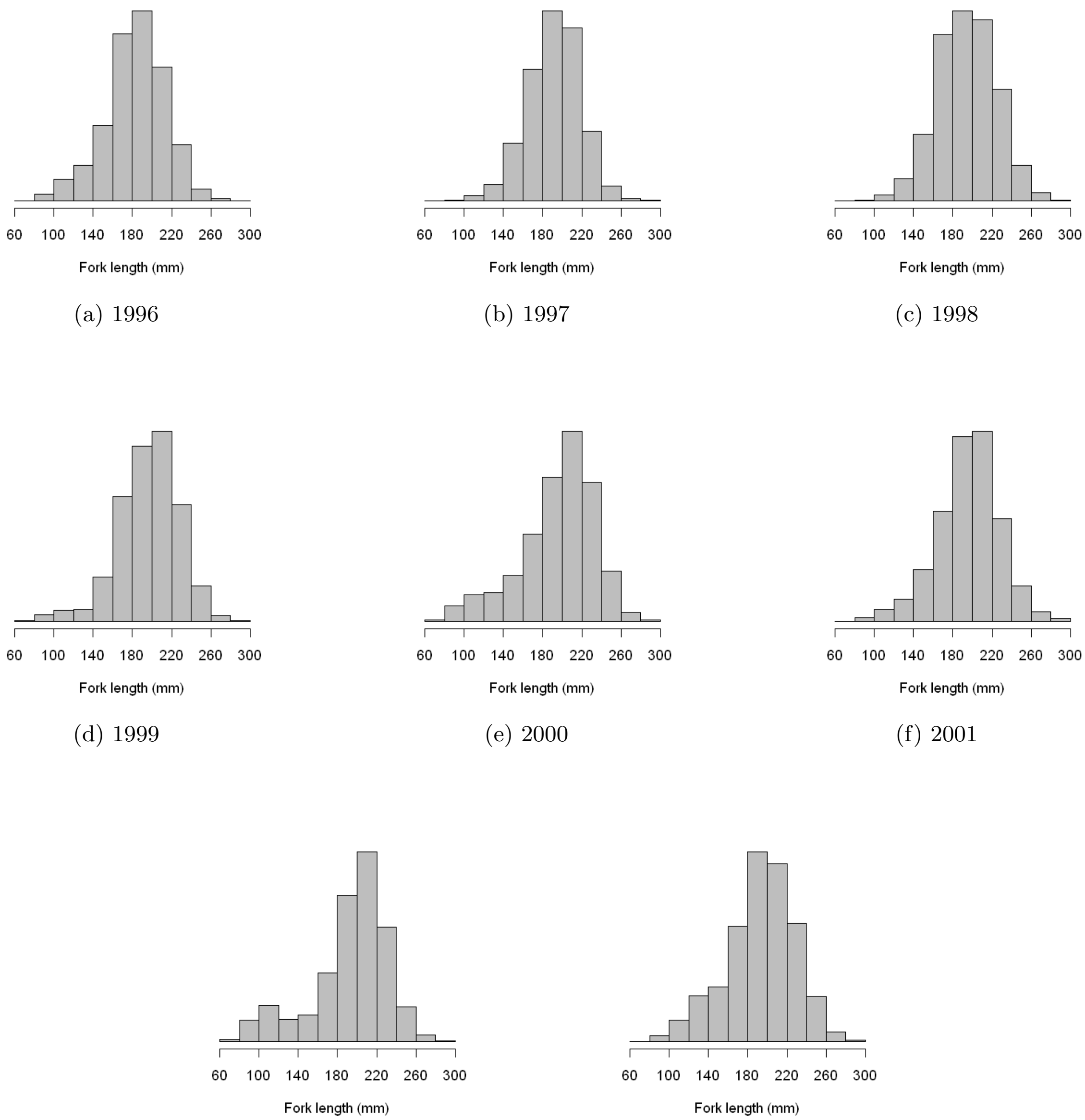


(a) 1996 (b) 1997 (c) 1998

(d) 1999 (e) 2000 (f) 2001

(g) 2002 (h) 2003

Figure 3.4: Fork length (mm) at tagging for summer Chinook salmon releases. Size-at-tagging data were not available for all tagged fish in all years. Frequency distributions represent the following proportions of annual release groups: 1996 (100%); 1997 (99.9%); 1998 (100%); 1999 (100%); 2000 (99.6%); 2001 (99.9%); 2002 (98.9%); 2003 (24.8%).



(a) 1996 (b) 1997 (c) 1998

(d) 1999 (e) 2000 (f) 2001

(g) 2002 (h) 2003

Figure 3.5: Fork length (mm) at tagging for steelhead releases. Size-at-tagging data were not available for all tagged fish in all years. Frequency distributions represent the following proportions of annual release groups: 1996 (99.9%); 1997 (100%); 1998 (98.1%); 1999 (97.7%); 2000 (98.6%); 2001 (98.8%); 2002 (99.6%); 2003 (95.8%).

Table 3.1 identifies the number of tagged smolts transported at each dam. While transportation occurred at each of Lower Granite, Little Goose, Lower Monumental, and McNary dams, only Lower Granite and Little Goose transported enough tagged smolts ($\geq 5,000$) to be analyzed for transportation effects. Detection histories of smaller transport groups were censored at the transport dam. Censoring the detection histories of small transport groups enables us to use previous detections of those fish to estimate survival to the transport dams, without overfitting the model in an attempt to estimate transportation effects from small transport groups. The result of this censoring is that for each release group, transportation effects are estimated only for Lower Granite or Little Goose dams, or both (or neither, for steelhead). Performance measures that include all transport dams reflect transportation only at dams with analyzed transport groups, i.e., Lower Granite, Little Goose, or both.

Table 3.1: Number transported at each transport dam. CLR = Clearwater River; SNK = Snake River (excluding Clearwater); SNB = Snake River Basin (sum of Snake and Clearwater Rivers). Bolded transport groups were analyzed, while all others were censored at transport dam because of small group size ($< 5,000$).

			Number Transported			
Release Year	**Species**	**Release Area**	**LGR**	**LGS**	**LMO**	**MCN**
1996	Spring Chinook	CLR	352	159	137	0
		SNK	346	158	95	4
		SNB	698	317	232	4
	Summer Chinook	SNB	222	74	114	3
	Steelhead	SNB	482	282	137	9
1997	Spring Chinook	CLR	2,165	52	45	2
		SNK	**11,436**	205	277	2
		SNB	**13,601**	257	322	4
	Summer Chinook	SNB	**10,218**	157	163	4
	Steelhead	SNB	1,087	102	340	5
1998	Spring Chinook	CLR	**9,115**	4,018	352	58
		SNK	**22,959**	4,137	943	68
		SNB	**32,074**	**8,155**	1,295	126
	Summer Chinook	SNB	**8,508**	1,054	372	23
	Steelhead	SNB	562	639	457	22
1999	Spring Chinook	CLR	4,650	3,667	500	6
		SNK	**13,460**	**7,273**	828	30

Table 3.1 (continued)

Release Year	Species	Release Area	Number Transported LGR	LGS	LMO	MCN
	Spring Chinook	SNB	**18,110**	**10,940**	1,328	36
	Summer Chinook	SNB	4,373	**5,034**	172	2
	Steelhead	SNB	609	274	308	4
2000	Spring Chinook	CLR	**9,509**	**5,452**	2,497	9
		SNK	**13,437**	**6,827**	2,160	6
		SNB	**22,946**	**12,279**	4,657	15
	Summer Chinook	SNB	**8,308**	3,193	873	17
	Steelhead	SNB	294	107	184	20
2001	Spring Chinook	CLR	**15,788**	3,915	590	58
		SNK	**22,082**	**5,089**	887	160
		SNB	**37,870**	**9,004**	1,477	218
	Summer Chinook	SNB	**11,605**	2,580	483	89
	Steelhead	SNB	154	72	107	33
2002	Spring Chinook	CLR	3,992	4,261	777	430
		SNK	**8,097**	**8,040**	2,502	1,544
		SNB	**12,089**	**12,301**	3,279	1,974
	Summer Chinook	SNB	4,212	4,136	297	236
	Steelhead	SNB	65	58	160	30
2003	Spring Chinook	CLR	**6,922**	4,169	1,131	210
		SNK	**40,682**	**17,622**	2,283	533
		SNB	**47,604**	**21,791**	3,414	743
	Summer Chinook	SNB	**9,309**	4,553	1,030	205
	Steelhead	SNB	1,999	1,506	812	28

Figures 3.6 to 3.10 show the number of fish in the release groups that were transported at each of the four transport dams from 1996 through 2003. Only dam-specific transport groups of at least 5,000 fish were analyzed in this report. These figures show that for the most part, only Lower Granite transportation is analyzed here. In some cases, Little Goose transportation is also analyzed. PIT-tagged hatchery steelhead were transported in very low numbers from 1996 to 2003, so no transportation analysis could be performed for steelhead for those years.

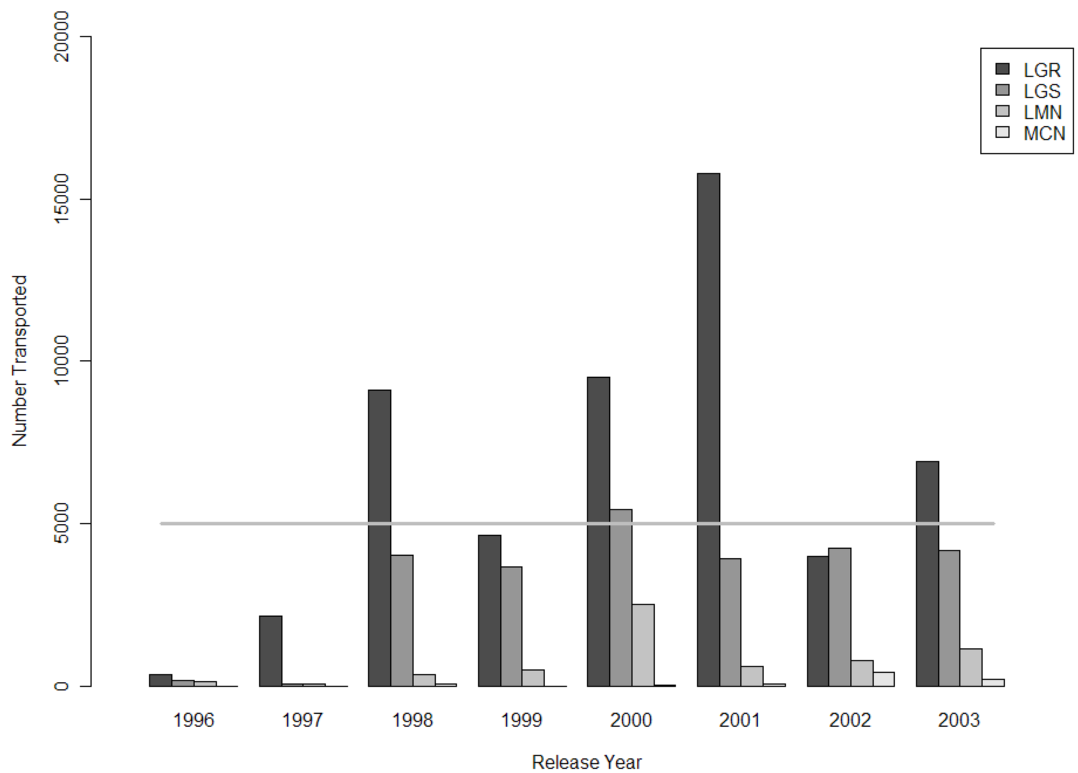


Figure 3.6: Number of PIT-tagged hatchery spring Chinook salmon from the Clearwater River Basin (release area CLR) transported from each dam from 1996 to 2003. Only dam-specific transport groups of at least 5,000 were analyzed.

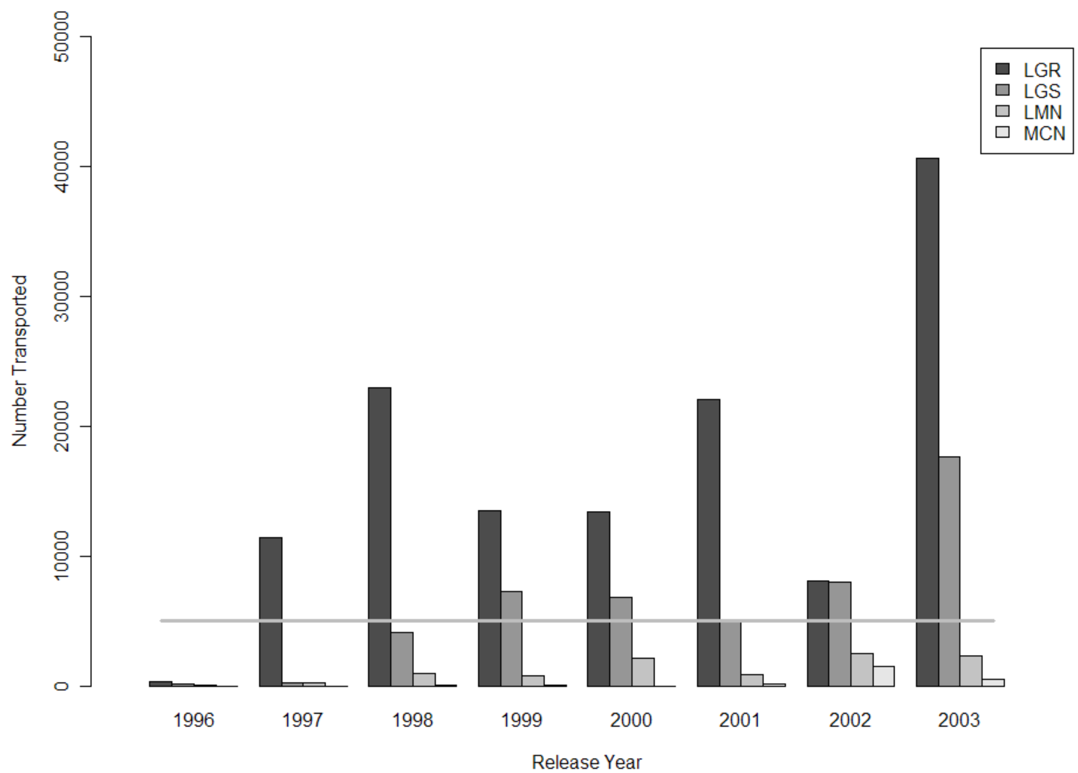


Figure 3.7: Number of PIT-tagged hatchery spring Chinook salmon from the Snake River (release area SNK) transported from each dam from 1996 to 2003. Does not include Clearwater fish. Only dam-specific transport groups of at least 5,000 were analyzed.

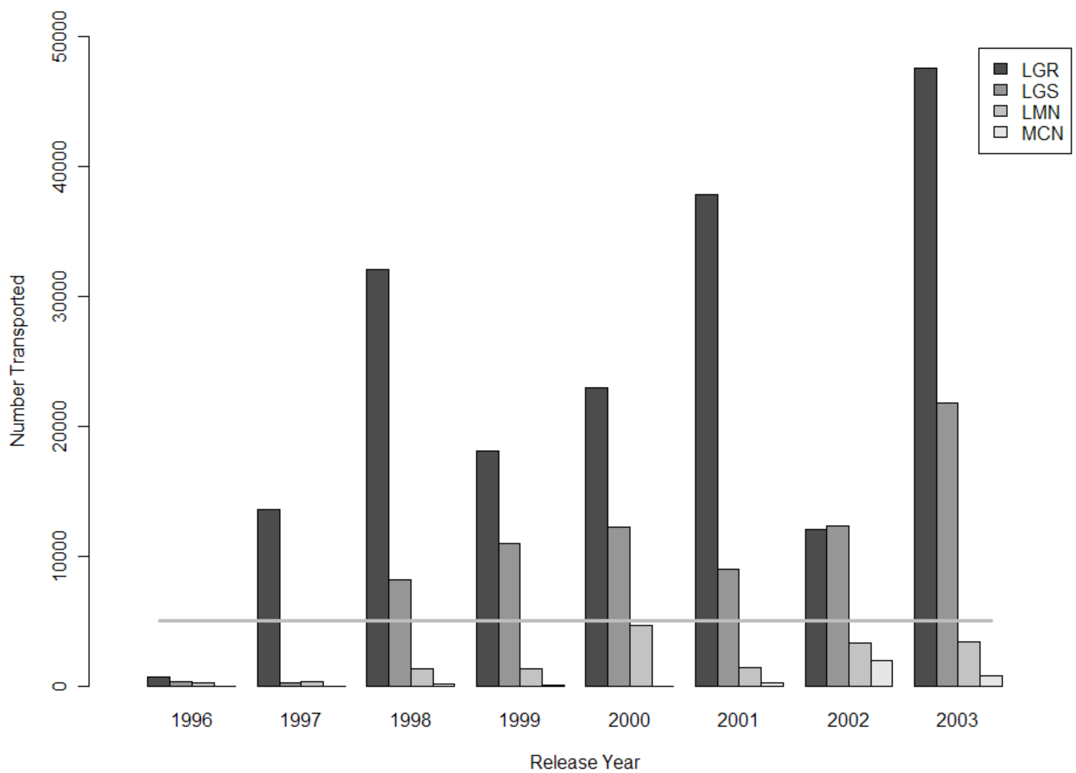


Figure 3.8: Number of PIT-tagged hatchery spring Chinook salmon from the Snake River Basin (release area SNB) transported from each dam from 1996 to 2003. Includes Clearwater fish. Only dam-specific transport groups of at least 5,000 were analyzed.

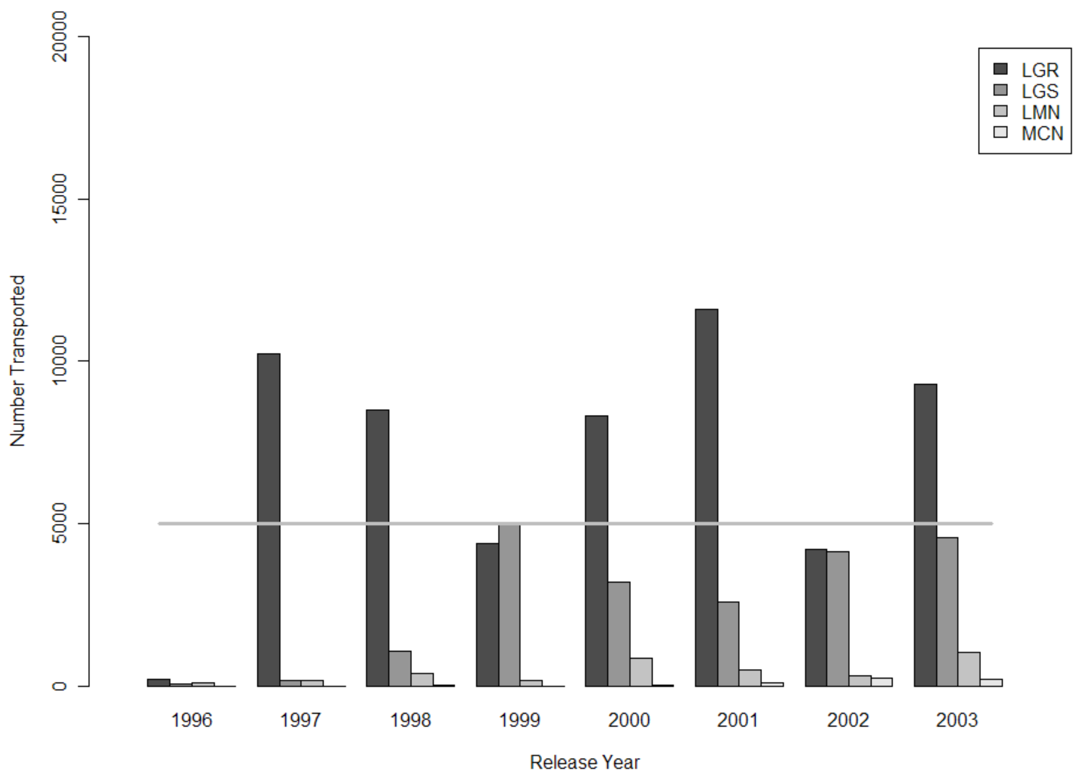


Figure 3.9: Number of PIT-tagged hatchery Summer Chinook salmon transported from each dam from 1996 to 2003. Only dam-specific transport groups of at least 5,000 were analyzed.

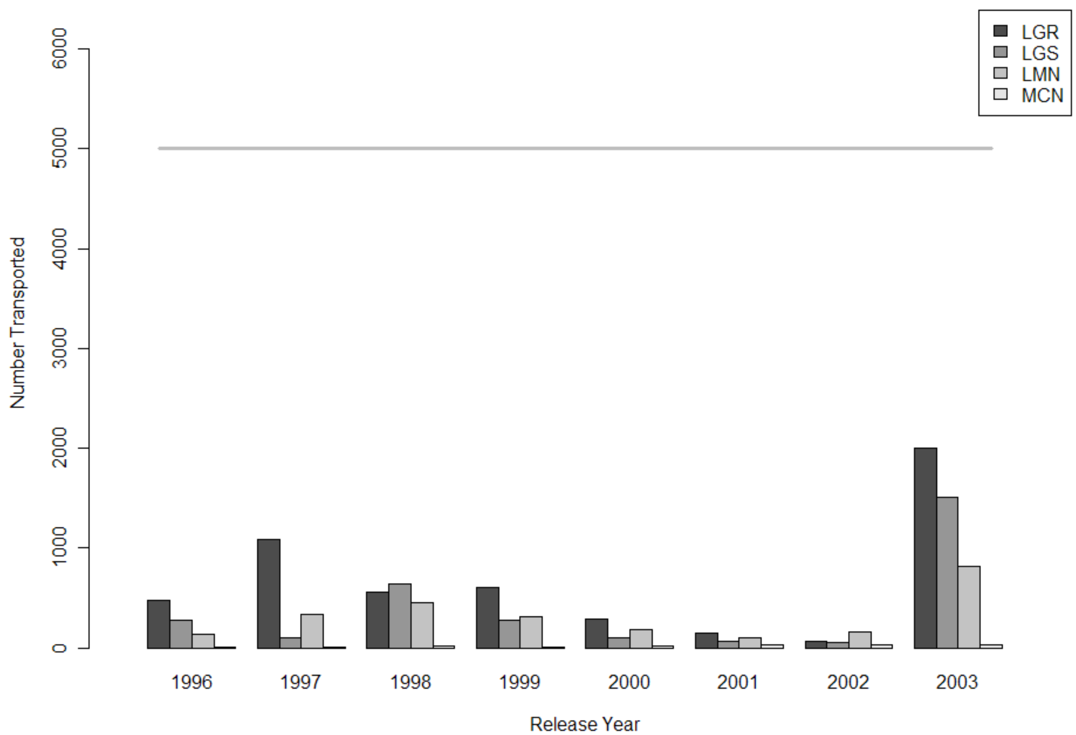


Figure 3.10: Number of PIT-tagged hatchery steelhead transported from each dam from 1996 to 2003. With all dam-specific transport groups smaller than 5,000 tagged individuals, no transportation effects were estimated for hatchery Snake River steelhead.

Figures 3.11 to 3.15 show the numbers of adults detected for each release group, categorized by transport group: transported from Lower Granite, transported from Little Goose, or not transported ("inriver"). These numbers reflect the total number of unique adults detected at any of the adult detection sites for the release group, including adults detected only at Bonneville or only at Lower Granite.

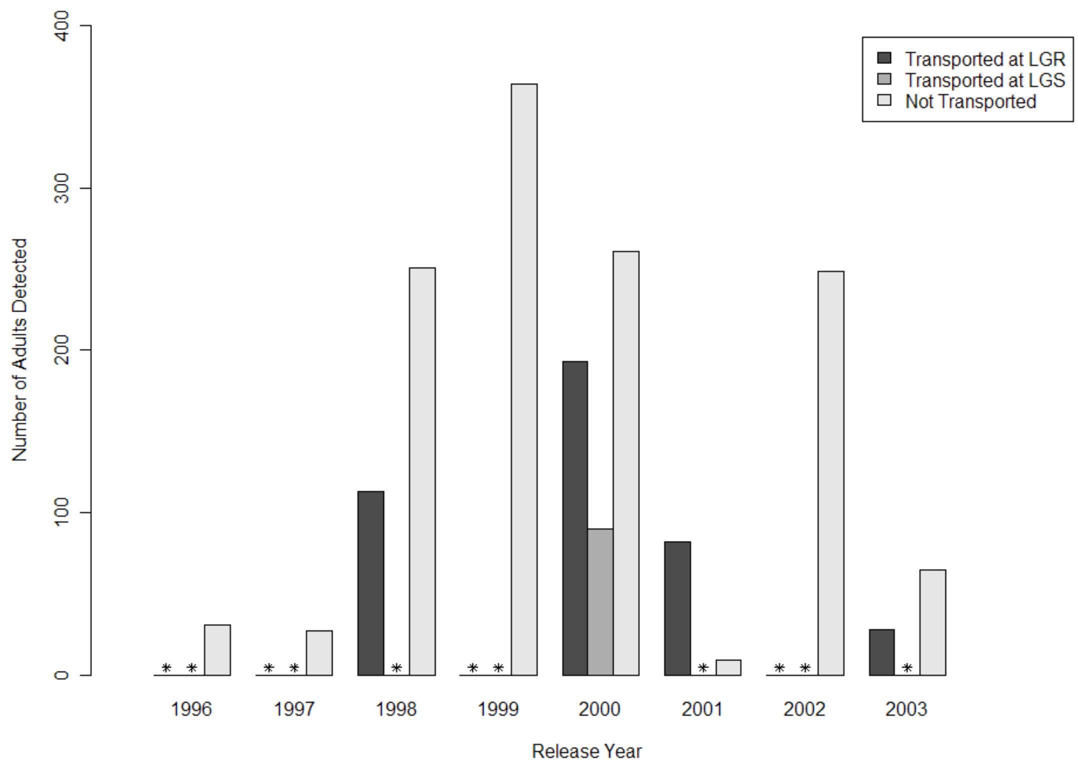


Figure 3.11: Number of unique PIT-tagged hatchery spring Chinook salmon from the Clearwater River Basin (release area CLR) detected as adults (at any detection site), categorized by transport group, for release years 1996 to 2003. The $*$ symbol for a transport dam signifies that no transport group was analyzed for that dam.

Table 3.2 gives the number of returning adults that were detected as age-1-ocean fish. The age-1-ocean Chinook ("jacks") were not included in estimates of performance measures that relate to adult returns, such as SAR, the ocean return probability, adult upriver survival, T/I, and D. On the other hand, the proportion of returning steelhead that return as age-1-ocean fish is often high, and includes both males and females, so performance measures for steelhead include the age-1-ocean fish (Williams et al. 2005).

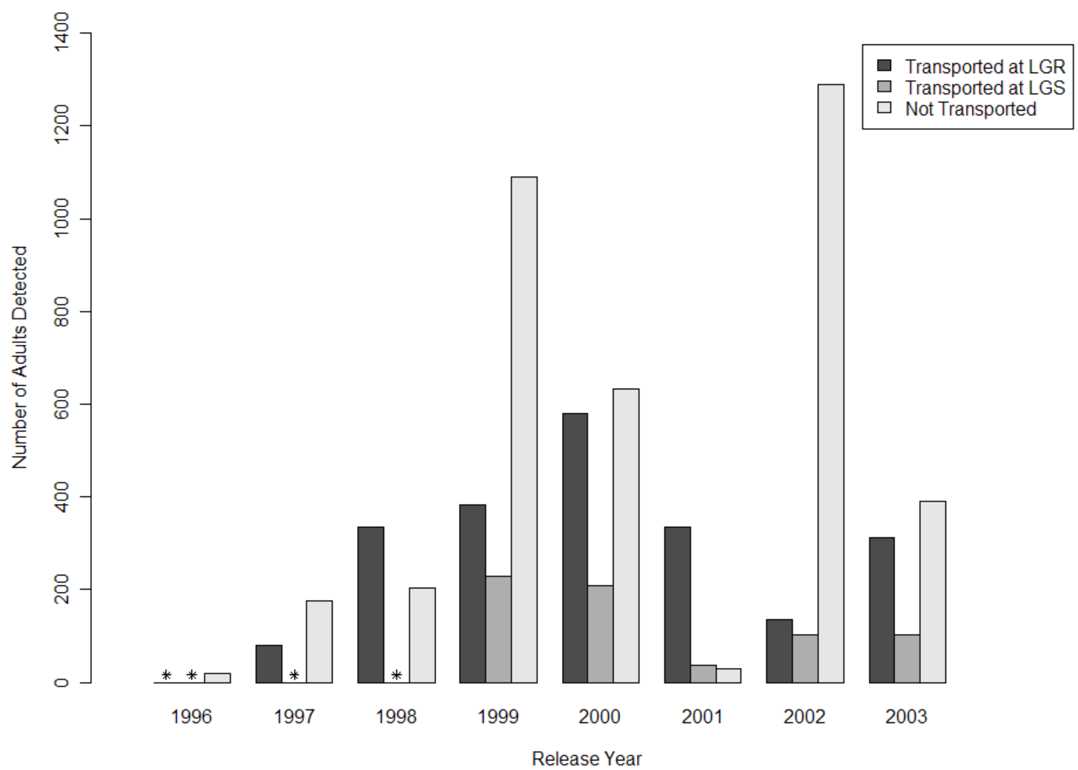


Figure 3.12: Number of unique PIT-tagged hatchery spring Chinook salmon from the Snake River (release area SNK) detected as adults (at any detection site), categorized by transport group, for release years 1996 to 2003. The $*$ symbol for a transport dam signifies that no transport group was analyzed for that dam.

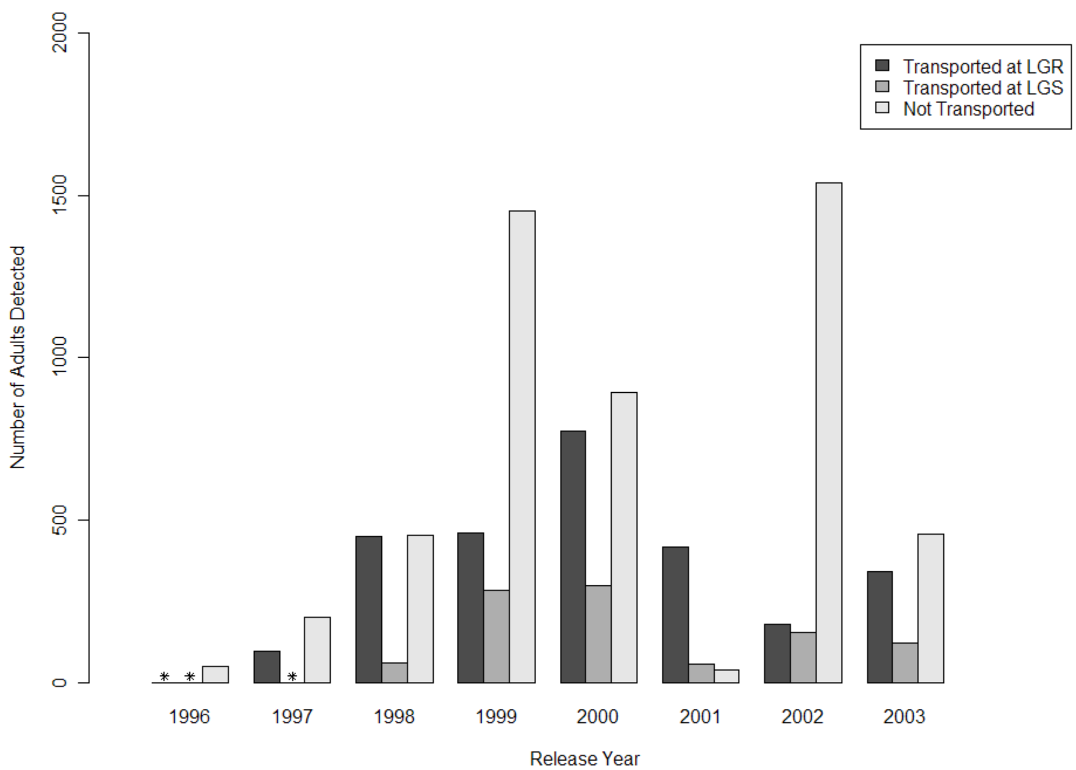


Figure 3.13: Number of unique PIT-tagged hatchery spring Chinook salmon from the Snake River Basin (release area SNB) detected as adults (at any detection site), categorized by transport group, for release years 1996 to 2003. The $*$ symbol for a transport dam signifies that no transport group was analyzed for that dam.

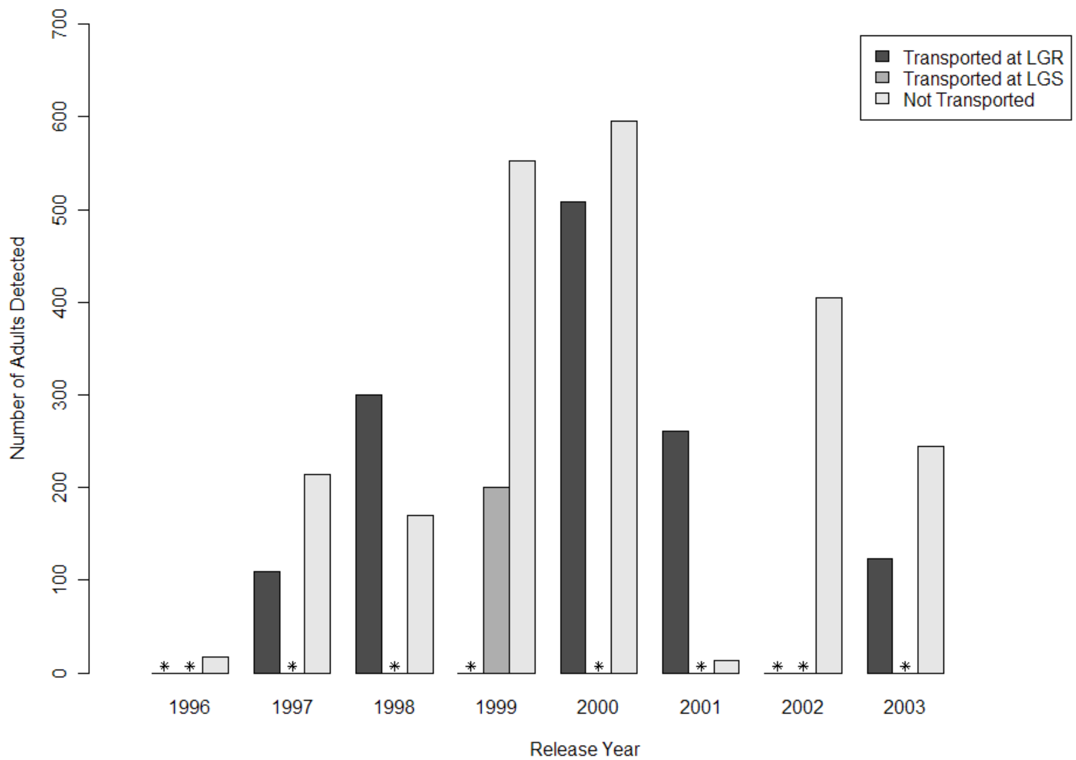


Figure 3.14: Number of unique PIT-tagged hatchery Summer Chinook salmon detected as adults (at any detection site), categorized by transport group, for release years 1996 to 2003. The $*$ symbol for a transport dam signifies that no transport group was analyzed for that dam.

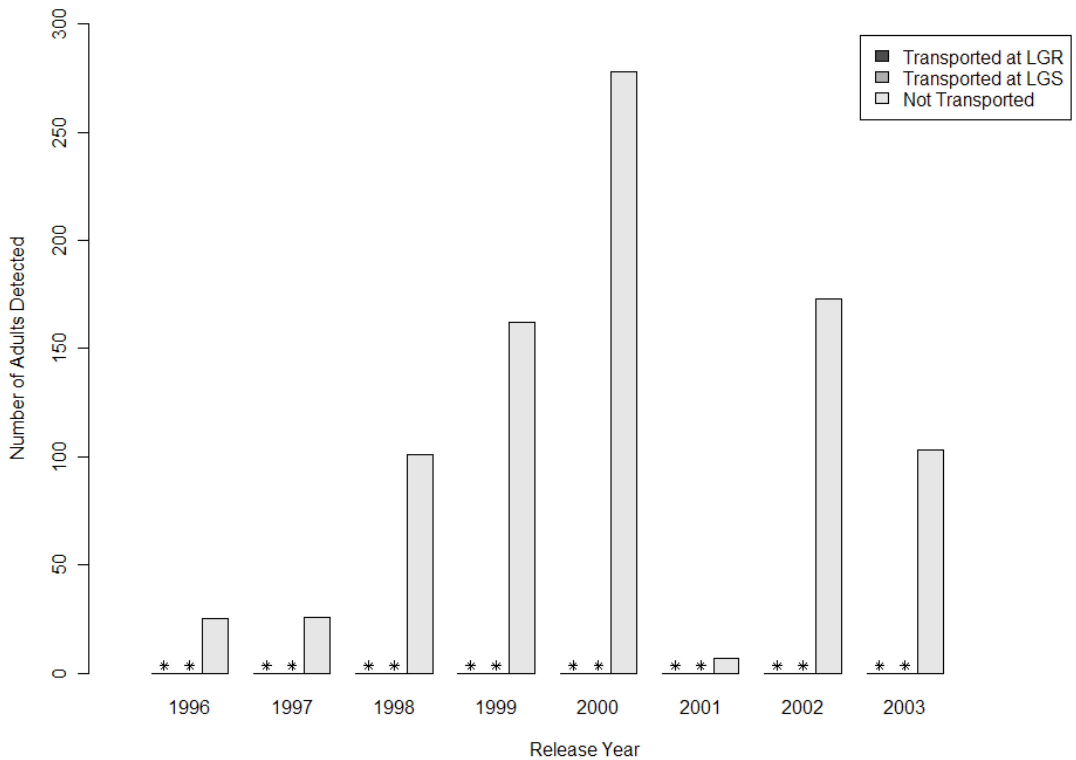


Figure 3.15: Number of unique PIT-tagged hatchery steelhead detected as adults (at any detection site), categorized by transport group, for release years 1996 to 2003. The $*$ symbol for a transport dam signifies that no transport group was analyzed for that dam.

Table 3.2: The percentage of the returning adults that return as age-1-ocean fish ("jacks" for Chinook). Values in parentheses are the numbers of adult detections (including age-1-ocean detections) for the row above. The average is the (unweighted) arithmetic average of the percentage. Release areas are: CLR = Clearwater River; SNK = Snake River (excluding Clearwater); SNB = Snake River Basin (sum of Snake and Clearwater Rivers).

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	0.0%	3.7%	11.3%	3.3%	0.6%	15.4%	15.3%	5.4%	6.9%
		(31)	(27)	(364)	(364)	(544)	(91)	(249)	(93)	
Spring Chinook	SNK	5.3%	10.2%	12.8%	26.9%	11.9%	12.9%	16.7%	23.3%	15.0%
		(19)	(254)	(539)	(1,701)	(1,422)	(402)	(1,529)	(807)	
Spring Chinook	SNB	2.0%	9.0%	12.1%	21.6%	8.7%	13.1%	16.6%	21.0%	13.0%
		(50)	(299)	(963)	(2,197)	(1,966)	(513)	(1,874)	(919)	
Summer Chinook	SNB	0.0%	7.7%	20.4%	12.3%	13.9%	22.9%	21.7%	32.1%	16.4%
		(17)	(323)	(470)	(754)	(1,104)	(275)	(405)	(368)	
Steelhead	SNB	56.0%	65.4%	83.2%	48.8%	65.1%	42.9%	66.5%	50.5%	59.8%
		(25)	(26)	(101)	(162)	(278)	(7)	(173)	(103)	

Table 3.3 summarizes the sizes of release groups and transport groups, and the number of adults detected at Lower Granite by transport group. After removing erroneous tags as described in Section 2.1.3, annual release groups ranged in size from 20,433 for the 1997 release of spring Chinook in the Clearwater River (release area CLK) to 304,850 for the 2003 release of spring Chinook in the Snake River Basin (release area SNB; Table 3.3). The types and numbers of erroneous tags that were removed are detailed in Tables C.8 to C.12.

Table 3.3: Size of release groups after removing erroneous tags, size of transport groups analyzed, and number of adults detected at Lower Granite by juvenile migration method (not transported, LGR transport, or LGS transport). CLR = Clearwater River; SNK = Snake River (excluding Clearwater); SNB = Snake River Basin (sum of Snake and Clearwater Rivers). Chinook adult counts do not include age-1-ocean fish (jacks); steelhead adult counts include age-1-ocean fish.

			Number of Smolts			Number of Adults at LGR			
Release Year	**Species**	**Release Area**	**Release Group**	**LGR Transp.**	**LGS Transp.**	**Not Transp.**	**LGR Transp.**	**LGS Transp.**	**Total**
1996	Spring Chinook	CLR	36,232	0	0	31	-	-	31
		SNK	31,264	0	0	18	-	-	18
		SNB	67,496	0	0	49	-	-	49
	Summer Chinook	SNB	28,062	0	0	17	-	-	17
	Steelhead	SNB	28,174	0	0	25	-	-	25
1997	Spring Chinook	CLR	20,433	0	0	26	-	-	26
		SNK	94,624	11,436	0	160	68	-	228
		SNB	115,057	13,601	0	186	86	-	272
	Summer Chinook	SNB	85,020	10,218	0	196	102	-	298
	Steelhead	SNB	33,754	0	0	26	-	-	26
1998	Spring Chinook	CLR	52,179	9,115	0	225	98	-	323
		SNK	109,514	22,959	0	171	299	-	470
		SNB	161,693	32,074	8,155	396	397	53	846
	Summer Chinook	SNB	50,261	8,508	0	125	249	-	374
	Steelhead	SNB	30,312	0	0	101	-	-	101
1999	Spring Chinook	CLR	55,061	0	0	333	-	-	333
		SNK	125,024	13,460	7273	645	328	193	1,166

Table 3.3 (continued)

Release Year	Species	Release Area	Number of Smolts: Release Group	Number of Smolts: LGR Transp.	Number of Smolts: LGS Transp.		Number of Adults at LGR: Not Transp.	Number of Adults at LGR: LGR Transp.	Number of Adults at LGR: LGS Transp.	Total
	Spring Chinook	SNB	180,085	18,110	10,940		978	387	243	1,608
	Summer Chinook	SNB	51,172	0	5,034		455	-	161	616
	Steelhead	SNB	38,697	0	0		138	-	-	138
2000	Spring Chinook	CLR	50,355	9,509	5,452		197	111	62	370
		SNK	81,478	13,437	6,827		458	364	143	965
		SNB	131,832	22,946	12,279		655	475	205	1,335
	Summer Chinook	SNB	58,479	8,308	0		447	371	-	818
	Steelhead	SNB	36,197	0	0		199	-	-	199
2001	Spring Chinook	CLR	59,490	15,788	0		7	54	-	61
		SNK	102,765	22,082	5,089		19	221	24	264
		SNB	162,255	37,870	9,004		26	275	41	342
	Summer Chinook	SNB	59,588	11,605	0	0		166	-	175
	Steelhead	SNB	30,786	0	0		3	-	-	3
2002	Spring Chinook	CLR	61,650	0	0		184	-	-	184
		SNK	241,652	8,097	8,040		881	85	71	1,037
		SNB	303,302	12,089	12,301		1,065	109	102	1,276
	Summer Chinook	SNB	68,484	0	0		255	-	-	255
	Steelhead	SNB	30,903	0	0		135	-	-	135
2003	Spring Chinook	CLR	61,311	6,922	0		51	20	-	71

Table 3.3 (continued)

			Number of Smolts			Number of Adults at LGR			
Release Year	**Species**	**Release Area**	**Release Group**	**LGR Transp.**	**LGS Transp.**	**Not Transp.**	**LGR Transp.**	**LGS Transp.**	**Total**
	Spring Chinook	SNK	243,539	40,682	17,622	249	187	69	505
		SNB	304,850	47,604	21,791	300	207	81	588
	Summer Chinook	SNB	87,654	9,309	0	116	64	-	180
	Steelhead	SNB	31,863	0	0	76	-	-	76

Chapter 4

Results

Plots of the estimated performance measures and results of additional analyses are presented in this chapter. Appendix G provides tables of point estimates and standard errors for the performance measures. Confidence intervals on plots have width equal to $\pm 1.96 \times$SE. Further results are available online at `http://www.cbr.washington.edu/trends/roster.php`.

Sets of results for the three release areas of spring Chinook salmon are shown together. The release area abbreviations are: CLR = Clearwater River, SNK = Snake River (excluding the Clearwater), and SNB = Snake River Basin (equivalent to CLR and SNK combined). More information on the release areas is given online at `http://www.cbr.washington.edu/trends/roster.php` and in Appendix C.

Estimates of performance measures that relate to the adult returns do not include the jack (age-1-ocean) age class for spring and summer Chinook salmon. Comparable estimates for steelhead include the age-1-ocean age class. Results for Chinook that include jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`. Reported means (averages) of survival estimates (e.g., SAR, S_J, O_{NT}, etc.) are unweighted arithmetic means across release years. Reported means of T/I and D estimates are unweighted geometric means across release years.

4.1 Smolt-to-Adult Return Ratio (SAR)

The smolt-to-adult return ratio (SAR) for a release group is the probability of survival from passing Lower Granite as a smolt to returning to Lower Granite as an adult, incorporating transportation probabilities, effects of transportation, juvenile inriver survival, the ocean return probability, and perceived adult upriver survival. Estimates of SAR are reported without the age-1-ocean (jack) age class for Chinook, but with the age-1-ocean age class for steelhead. The tagged estimator SAR estimates the LGR-LGR return probability for the tagged release group. The "untagged" estimator SAR^U estimates the LGR-LGR return probability for the untagged population, based on the tagging data under the assumption that the tagged population represents the untagged population with equal survival but different transportation rates. The distinction between the tagged and untagged SAR measures is that, unlike the tagged measure SAR, the untagged measure SAR^U is based on the assumption that all untagged fish are transported upon detection at transport dams (i.e., the model parameter $t_i = 1$ for transport dam i). The direct inference of the untagged measure SAR^U is to the (tagged) release group, had it been treated as untagged at the transport dams. Alternatively, SAR^U values estimate what the SAR of the tagged release group would have been under maximal transportation of tagged fish (i.e., no diversion back to the river, as occurs for some PIT-tagged fish) at the transport dams analyzed (i.e., those with at least 5,000 tagged fish transported). As a reminder, note the distinction in notation: SAR (non-italicized) represents the conceptual smolt-to-adult return ratio, SAR (italicized) is the tagged estimator of SAR, and SAR^U is the untagged estimator of SAR.

4.1.1 Hatchery Spring Chinook Salmon

The estimated value of the tagged smolt-to-adult return ratio ($\widehat{SAR}$) from Lower Granite to Lower Granite for hatchery spring Chinook salmon from the Snake River Basin (release area SNB; Figure 4.1; Table G.1) was highest for the 2000 release group ($\widehat{SAR} = 1.48\%$, $\widehat{SE} = 0.04\%$), and lowest for the 1996 release group ($\widehat{SAR} = 0.14\%$, $\widehat{SE} = 0.02\%$), with a mean value of 0.71% ($\widehat{SE} = 0.18\%$) for release groups from 1996 to 2003. The highest estimated tagged SAR value for hatchery Clearwater spring Chinook was for the 1999 release group ($\widehat{SAR} = 1.07\%$, $\widehat{SE} = 0.05\%$), and the lowest were for the 1996 and 2001 release groups ($\widehat{SAR} = 0.15\%$, $\widehat{SE} = 0.03\%$ for both release groups). The mean $\widehat{SAR}$ for Clearwater spring Chinook for release years 1996 to 2003 was 0.55% ($\widehat{SE} = 0.15\%$). For Snake River spring Chinook (release area SNK), the estimated value of tagged SAR was highest for the 2000 release group ($\widehat{SAR} = 1.82\%$, $\widehat{SE} = 0.07\%$) and lowest in 1996 ($\widehat{SAR} = 0.13\%$, $\widehat{SE} = 0.03\%$), with a mean value of 0.78% ($\widehat{SE} = 0.21\%$) for release years 1996 to 2003. In most years, estimates of SAR were lower for Clearwater spring Chinook than for Snake River (SNK) spring Chinook. These estimates of SAR do not include the jack age class. Estimates of SAR including the jack age class are available online at `http://www.cbr.washington.edu/trends/roster.php`.

Estimated values of untagged SAR (SAR^U) for hatchery spring Chinook salmon followed a similar pattern to estimates of the tagged SAR (SAR). However, point estimates of SAR^U were generally slightly higher than comparable point estimates of SAR from 1998 to 2003, using the assumption that all untagged fish were transported from the juvenile bypass systems at the transport dams, and using the estimated effects of juvenile transportation on adult return rates of tagged fish (see Figures 4.31, 4.32, 4.33, and 4.34). The estimated value of the untagged SAR (SAR^U) for hatchery spring Chinook from the Snake River Basin (release area SNB; Figure 4.2; Table G.2) was highest for the 1999 release group ($\widehat{SAR^U} = 1.73\%$, $\widehat{SE} = 0.06\%$) and lowest for the 1996 release group ($\widehat{SAR^U} = 0.14\%$, $\widehat{SE} = 0.02\%$). The mean estimate of SAR^U for SNB spring Chinook for release groups from 1996 to 2003 was 0.82% ($\widehat{SE} = 0.20\%$). The estimated value of the

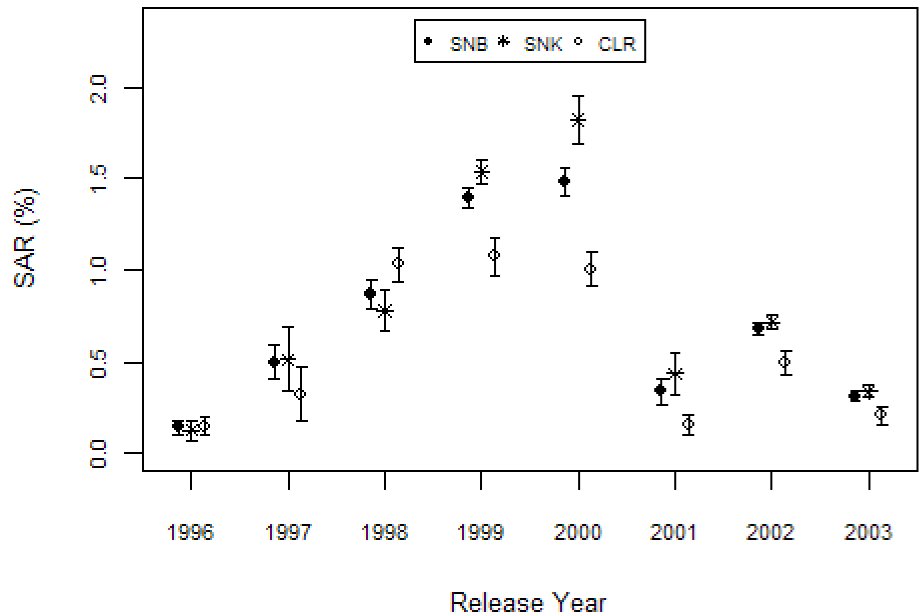


Figure 4.1: Estimated tagged SAR for hatchery spring Chinook salmon ($\widehat{SAR}$), with 95% confidence intervals. Both transported and nontransported fish are included in these SAR estimates. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater.

untagged SAR (SAR^U) for hatchery Clearwater spring Chinook was highest for the 1999 release group ($\widehat{SAR^U}$ = 1.07%, $\widehat{SE}$ = 0.05%), and lowest for the 1996 release group ($\widehat{SAR^U}$ = 0.15%, $\widehat{SE}$ = 0.03%), with a mean estimate of 0.58% ($\widehat{SE}$ = 0.15%) for release years 1996 to 2003. The highest estimate of SAR^U for Snake River spring Chinook (release area SNK) was for the 2000 release group ($\widehat{SAR^U}$ = 2.03%, $\widehat{SE}$ = 0.08%), and the lowest estimate was for the 1996 release group ($\widehat{SAR^U}$ = 0.13%, $\widehat{SE}$ = 0.03%). The average $\widehat{SAR^U}$ estimate for SNK spring Chinook for release years 1996 to 2003 was 0.95% ($\widehat{SE}$ = 0.25%). These estimates of SAR^U do not include jacks; results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`. The direct inference from these values and the values in Figure 4.2 and Table G.2 is to the tagged release group, had they been transported at untagged rates. If there are differences in survival between tagged and untagged fish, then the values in Figure 4.2 will be biased for untagged hatchery spring Chinook salmon. In particular, if PIT-tagged fish have lower survival than untagged fish, then the values in Figure 4.2 will be negatively biased for untagged hatchery spring Chinook salmon.

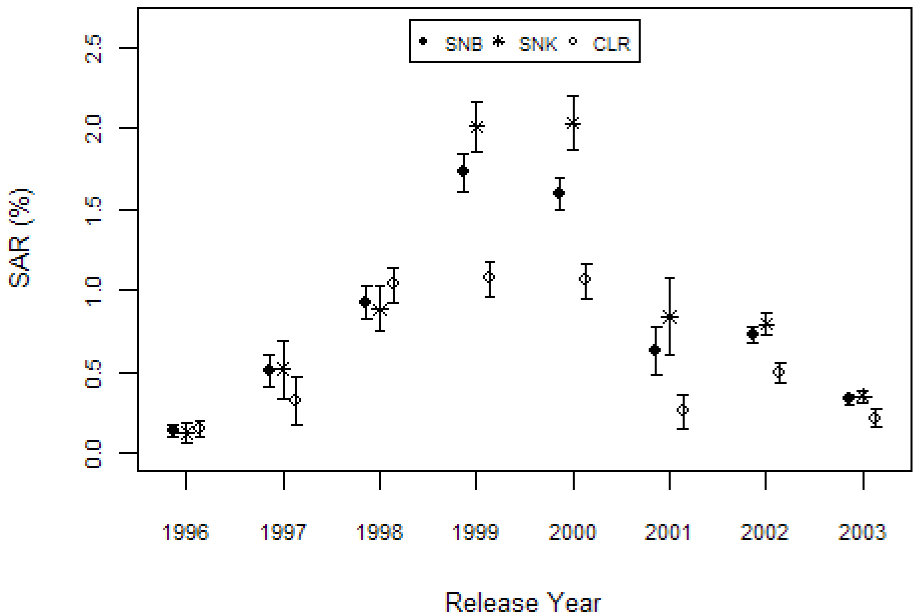


Figure 4.2: Estimated untagged SAR for hatchery spring Chinook salmon ($\widehat{SAR^U}$), with 95% confidence intervals. Both transported and nontransported fish are included in these estimates. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Untagged SAR estimates are based on survival estimates from transported and nontransported tagged fish, using the assumption of 100% transportation of untagged fish upon first detection at any dam with an analyzed transport group for the release year.

4.1.2 Hatchery Summer Chinook Salmon

Estimates of tagged SAR (SAR) for hatchery summer Chinook salmon (Figure 4.3; Table G.1) followed a pattern similar to tagged spring Chinook salmon, but summer Chinook estimates tended to be somewhat higher than the spring Chinook estimates. Summer Chinook had point estimates of SAR greater than 2% for the 1999 and 2000 release years, with the highest estimate for the 2000 release year ($\widehat{SAR} = 2.59\%$, $\widehat{SE} = 0.10\%$) and the lowest estimate for the 1996 release year ($\widehat{SAR} = 0.11\%$, $\widehat{SE} = 0.03\%$). The average $\widehat{SAR}$ for hatchery summer Chinook for release years from 1996 to 2003 was 1.15% ($\widehat{se} = 0.31\%$). Very low detections of nontransported fish at the final juvenile detection site and as adults for the 1996 and 2001 release groups made fitting the full ROSTER model for these years impossible. Thus, estimates for the 1996 and 2001 release years are heuristic estimates that use the juvenile portion of the ROSTER model (see Appendix E.5 and Table F.4). No estimates include the jack age class; estimates including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

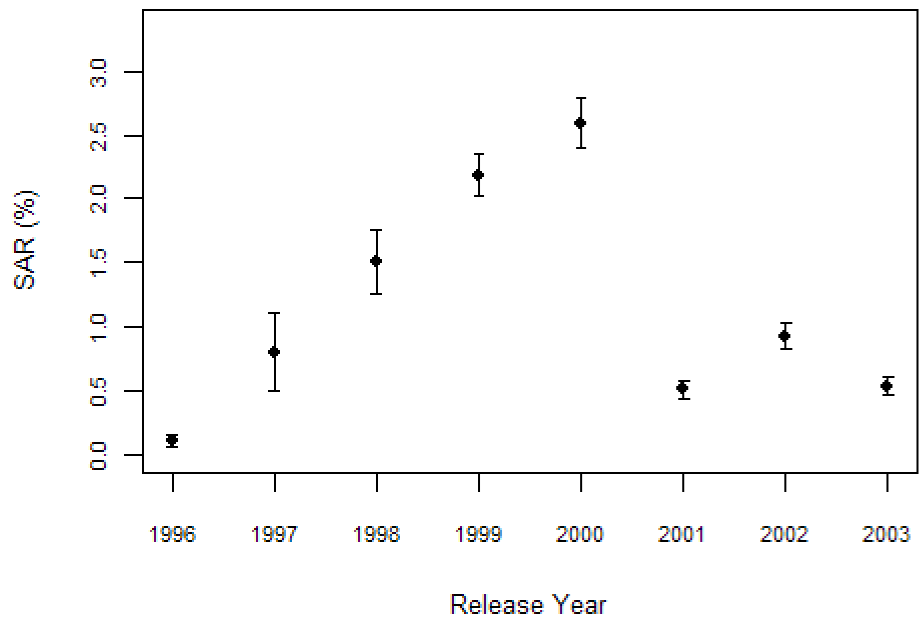


Figure 4.3: Estimated tagged SAR for hatchery summer Chinook salmon ($\widehat{SAR}$), with 95% confidence intervals. Both transported and nontransported fish are included in these estimates. Estimates do not include jacks. Estimates for the 1996 and 2001 release years are heuristic estimates, produced outside the full ROSTER model.

Point estimates of untagged SAR (SAR^U) for hatchery summer Chinook salmon (Figure 4.4; Table G.2) followed a pattern similar to point estimates of tagged SAR, but were generally higher than the tagged SAR estimates. The highest estimate of SAR^U for hatchery summer Chinook was for the 2000 release group ($\widehat{SAR^U} = 2.96\%$, $\widehat{SE} = 0.12\%$), and the lowest was for the 1996 release year ($\widehat{SAR^U} = 0.11\%$, $\widehat{SE} = 0.03\%$). The average estimate of untagged SAR for hatchery summer Chinook salmon for release years 1996 to 2003 was 1.34% ($\widehat{SE} = 0.34\%$). These estimates exclude jacks; estimates including jacks are available at `http://www.cbr.washington.edu/trends/roster.php`. Estimates for the 1996 and 2001 release years are heuristic estimates, produced outside the full ROSTER model (see Appendix E.5 and Table F.4). As with the untagged measures for spring Chinook salmon, inference from $\widehat{SAR^U}$ for summer Chinook is to the tagged release groups, had they been transported at the assumed rate of untagged fish (i.e., 100% transported from the JBS) at all analyzed transport dams. Had transportation been detrimental for summer Chinook, the untagged SAR estimates would have been lower than the tagged SAR estimates.

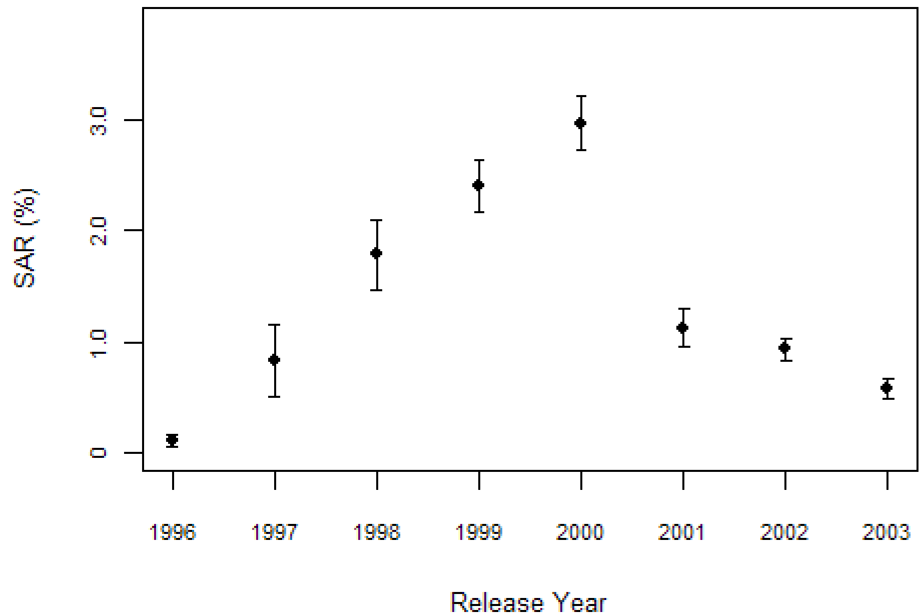


Figure 4.4: Estimates of untagged SAR for hatchery summer Chinook salmon ($\widehat{SAR^U}$), with 95% confidence intervals. Both transported and nontransported fish are included in these estimates. Estimates do not include jacks. Estimates for the 1996 and 2001 release years are heuristic estimates, produced outside the full ROSTER model. Untagged SAR estimates are based on survival estimates from transported and nontransported tagged fish, using the assumption of 100% transportation of untagged fish upon first detection at any dam with an analyzed transport group for the release year.

4.1.3 Hatchery Steelhead

Estimates of tagged SAR (SAR) for Snake River hatchery steelhead (Figure 4.5; Table G.1) followed a different pattern that Chinook estimates. The highest estimate of SAR for hatchery steelhead was for the 2000 release group ($\widehat{SAR} = 0.98\%$, $\widehat{SE} = 0.06\%$), and the lowest estimate was for the 2001 release group ($\widehat{SAR} = 0.03\%$, $\widehat{SE} = 0.01\%$). The average $\widehat{SAR}$ for hatchery steelhead for release years 1996 to 2003 was 0.45% ($\widehat{SE} = 0.11\%$). These results include the age-1-ocean age class; SAR estimates would be considerably lower if these fish were excluded. On average, the age-1-ocean age class made up about 60% of the returning adult steelhead detected (Table 3.2). Results excluding the age-1-ocean age class are available online at `http://www.cbr.washington.edu/trends/roster.php`. Estimates for release years 1998 and 2001 were heuristic estimates (see Appendix E.5 and Table F.5), estimated outside the full ROSTER model because of low numbers observed adults from these release years. Because no steelhead transport groups were analyzed, tagged and untagged SAR measures (i.e., SAR and SAR^U) are identical for hatchery steelhead from 1996 to 2003.

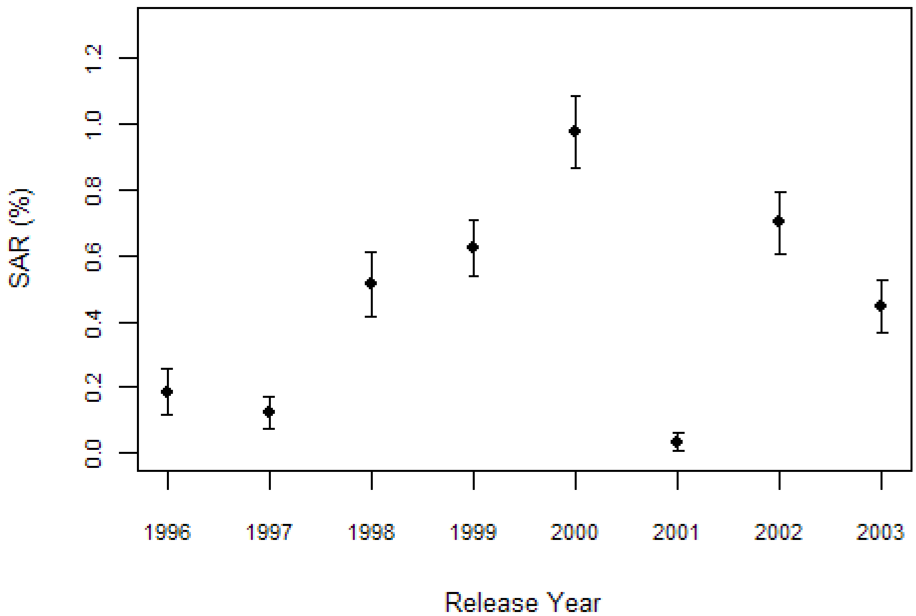


Figure 4.5: Estimated tagged SAR for hatchery steelhead ($\widehat{SAR}$), with 95% confidence intervals. No steelhead transport groups were analyzed, so these SAR estimates are based solely on nontransported fish. Age-1-ocean fish are included in these estimates. Low adult counts from release years 1998 and 2001 required SAR estimates for those release years to be computed heuristically, outside the full ROSTER model.

4.2 Juvenile Inriver Survival

Juvenile inriver survival, S_J, is the survival probability of nontransported smolts from Lower Granite to Bonneville. All juvenile and adult detection data are used to estimate this measure, including adult detections from the age-1-ocean age class.

4.2.1 Hatchery Spring Chinook Salmon

Estimates of juvenile inriver survival from LGR to BON (S_J) of hatchery spring Chinook salmon from the Snake River Basin (release area SNB; Figure 4.6; Table G.3) ranged from 35.5% ($\widehat{SE} =$ 10.0%) in 2001 to 73.1% ($\widehat{SE} = 4.7\%$) in 2002, with an average of 59.8% ($whSE = 4.3\%$) for release years 1996 to 2003. Juvenile detections at Bonneville and John Day were unavailable in 1996 and 1997, so estimates of S_J were extrapolated from estimates of survival to McNary on a per-project basis in 1996 and a per-detection site basis in 1997 (Table F.3). These extrapolations resulted in high uncertainty in the 1996 and 1997 estimates for SNB fish. For hatchery spring Chinook salmon from the Clearwater River, estimates of juvenile inriver survival ranged from 30.3% ($\widehat{SE} = 23.1\%$) in 1997 to 64.2% ($\widehat{SE} = 8.4\%$) in 2002. The average estimate of juvenile inriver survival for Clearwater spring Chinook for release years 1996 to 2003 was 49.2% ($\widehat{SE} = 4.9\%$). Juvenile detections at Bonneville and John Day were unavailable in 1996 and 1997, so estimates of S_J for Clearwater fish were extrapolated from estimates of survival to McNary on a per-river kilometer (RKM) basis in 1996 and a per-project basis in 1997 (Table F.1). These extrapolations resulted in high uncertainty in the 1996 and 1997 estimates for CLR fish. For Snake River hatchery Spring Chinook (release area SNK), estimates of juvenile inriver survival ranged from 38.0% ($\widehat{SE} = 11.6\%$) in 2001 to 83.3% ($\widehat{SE} = 45.6\%$) in 1996, with an average estimate of 64.9% ($\widehat{SE} = 4.9\%$) from 1996 to 2003. In 1996, juvenile detection was unavailable at Bonneville and John Day for SNK fish, so the estimate of juvenile inriver survival was extrapolated from survival estimated to McNary on a per-site basis for 1996 (see Table F.2). This extrapolation resulted in high uncertainty in the estimate of S_J for 1996.

4.2.2 Hatchery Summer Chinook Salmon

Estimates of juvenile inriver survival (S_J) for hatchery summer Chinook salmon (Figure 4.7; Table G.3) ranged from 51.8% ($\widehat{SE} = 4.0\%$) in 1999 to 73.4% ($\widehat{SE} = 17.0\%$) in 1998. Because of very low numbers of detections of nontransported fish at downstream smolt detectors and later as returning adults from the 1996 and 2001 release groups, juvenile inriver survival could not be estimated for these two release years. Low detection rates of smolts at Bonneville in 1998 made direct estimation of juvenile inriver survival impossible for that year; the estimate of S_J for 1998 was extrapolated from estimated survival to John Day on a per-site basis (see Table F.4). For all years with estimates (i.e., 1997 to 2000 and 2002 to 2003), the average estimated juvenile inriver survival for hatchery summer Chinook was 65.1% ($\widehat{SE} = 3.3\%$).

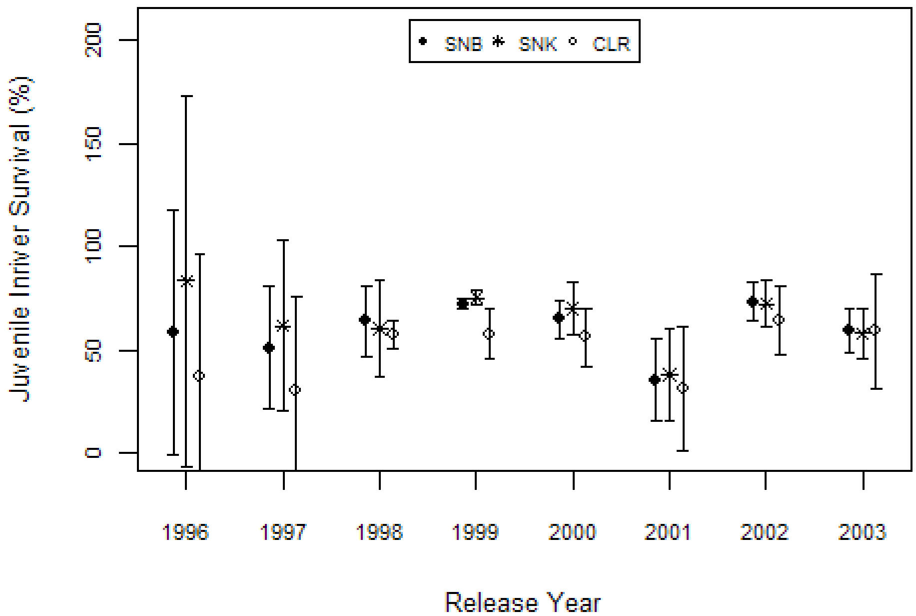


Figure 4.6: Estimated juvenile inriver survival for hatchery spring Chinook salmon ($\widehat{S_J}$), with 95% confidence intervals. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. The SNB estimates for 1996 and 1997 were extrapolated from estimated survival to McNary on a per-project and per-detection site basis, respectively. The CLR estimates for 1996 and 1997 were extrapolated from estimated survival to McNary on a per-river kilometer and per-project basis, respectively. The SNK estimate for 1996 was extrapolated from estimated survival to McNary on a per-site basis.

4.2.3 Hatchery Steelhead

Estimates of juvenile inriver survival for hatchery steelhead ranged from 23.9% ($\widehat{SE} = 2.5\%$) in 2000 to 47.9% ($\widehat{SE} = 6.6\%$) in 1999. Estimates were unavailable in 1998 and 2001 because of very low detections of nontransported fish as juveniles at downriver detection sites and as returning adults from those two release years. Low juvenile rates at Bonneville and John Day in 1996 prevented direct estimation of juvenile inriver survival for that release year; the estimate of S_J for 1996 was extrapolated on a per-RKM basis from estimated survival from McNary, resulting in high uncertainty in the 1996 estimate. The average estimated juvenile inriver survival of hatchery steelhead for release years 1996, 1997, 1999, 2000, 2002, and 2003 was 35.4% ($\widehat{SE} = 4.2\%$). These estimates do not include steelhead that overwintered in the hydrosystem during their juvenile outmigration.

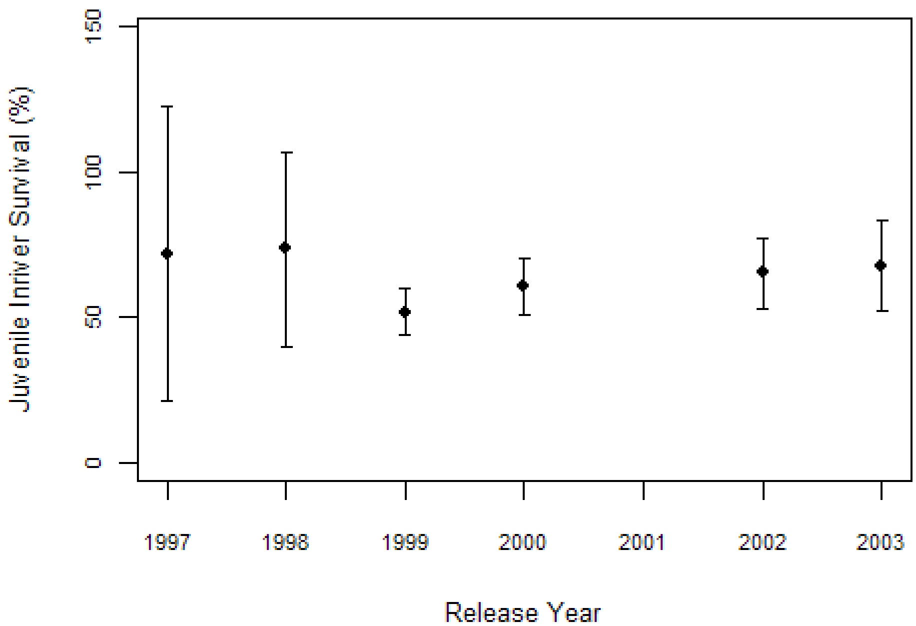


Figure 4.7: Estimated juvenile inriver survival for hatchery summer Chinook salmon ($\widehat{S_J}$), with 95% confidence intervals. The estimate for 1998 was extrapolated from survival to John Day on a per-site basis. Estimates were unavailable for the 1996 and 2001 release years because too few nontransported adults were detected from those release years.

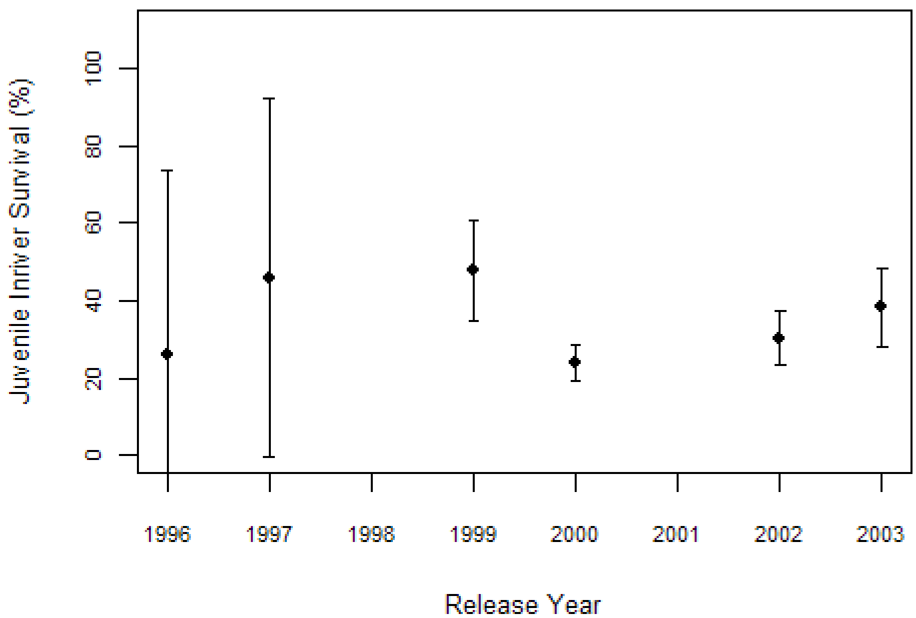


Figure 4.8: Estimated juvenile inriver survival for hatchery steelhead ($\widehat{S_J}$), with 95% confidence intervals. Estimates were not calculated for 1998 and 2001 because of very few detections of nontransported steelhead at downriver juvenile detectors and as returning adults from these two release years. The 1996 estimate was extrapolated on a per-river kilometer basis from estimated survival to McNary.

4.3 Ocean Return Probability

The ocean return probability is the probability of returning from Bonneville as a juvenile back to Bonneville as an adult. It includes survival between Bonneville and the mouth of the Columbia River for both juveniles and adults, as well as survival in the ocean. The ocean return probability is estimated separately for nontransported fish (O_{NT}), LGR-transport fish (O_{LGR}), and LGS-transport fish (O_{LGS}), assuming 98% survival of transported fish during transportation (i.e., on the barge or truck). The ocean return probability cannot be estimated for transport groups that were censored because of small size (i.e., groups $< 5,000$); this means that estimates of O_{LGR} and O_{LGS} are missing for some Chinook release groups and for all steelhead release groups. Additionally, estimates of ocean return probability are available only for release groups for which adult detection at Bonneville was available, i.e., for release groups from 1999 through 2003. Estimates of ocean return probability do not include jacks for Chinook, but do include the age-1-ocean age class for steelhead. Additional results are available online at `http://www.cbr.washington.edu/trends/roster.php`.

4.3.1 Hatchery Spring Chinook Salmon

Estimated values of the ocean return probability (O_{NT}) for nontransported hatchery spring Chinook from the Snake River Basin (release area SNB; Figure 4.9; Table G.4) were highest for the 2000 release group ($\widehat{O_{NT}} = 2.40\%$, $\widehat{SE} = 0.20\%$) and lowest for the 2001 release group ($\widehat{O_{NT}} = 0.20\%$, $\widehat{SE} = 0.07\%$), with a mean value of 1.24% ($\widehat{SE} = 0.42\%$) for release years 1999 to 2003. For nontransported hatchery Clearwater fish, the estimated ocean return probability was highest for the 1999 release group ($\widehat{O_{NT}} = 2.41\%$, $\widehat{SE} = 0.32\%$) and lowest for the 2001 release group ($\widehat{O_{NT}} = 0.15\%$, $\widehat{SE} = 0.09\%$), with a mean value of 1.22% ($\widehat{SE} = 0.48\%$) for release years from 1999 through 2003. For nontransported hatchery spring Chinook from the Snake River (release area SNK), the estimated ocean return probability was highest for the 2000 release group ($\widehat{O_{NT}} = 2.50\%$, $\widehat{SE} = 0.25\%$) and lowest for the 2001 release group ($\widehat{O_{NT}} = 0.23\%$, $\widehat{SE} = 0.09\%$), with a mean value of 1.28% ($\widehat{SE} = 0.42\%$) for release years from 1999 through 2003. For all three release area groups (CLR, SNK, and SNB), the estimate of the nontransported ocean return probability ($\widehat{O_{NT}}$) was less than or equal to the estimate of SAR for release year 2001. Because O_{NT} is a component of SAR, $\widehat{O_{NT}}$ is usually greater than $\widehat{SAR}$. However, it is possible for $\widehat{O_{NT}}$ to be greater than $\widehat{SAR}$ because SAR uses the ocean return probability from both transported and nontransported fish, while O_{NT} is restricted to nontransported fish. In 2001, most hatchery spring Chinook were transported, and transported fish had higher ocean return probabilities than nontransported fish (see Tables G.4, G.5, and G.6), resulting in estimates of SAR that were greater than (or equal to) estimates of O_{NT} for 2001. It should be noted that estimates of O_{NT} (and SAR) for Chinook do not include the age-1-ocean (jack) age class; results including the jack age class are available online at `http://www.cbr.washington.edu/trends/roster.php`.

Estimates of the ocean return probability (O_{LGR}) for LGR-transport spring Chinook from the

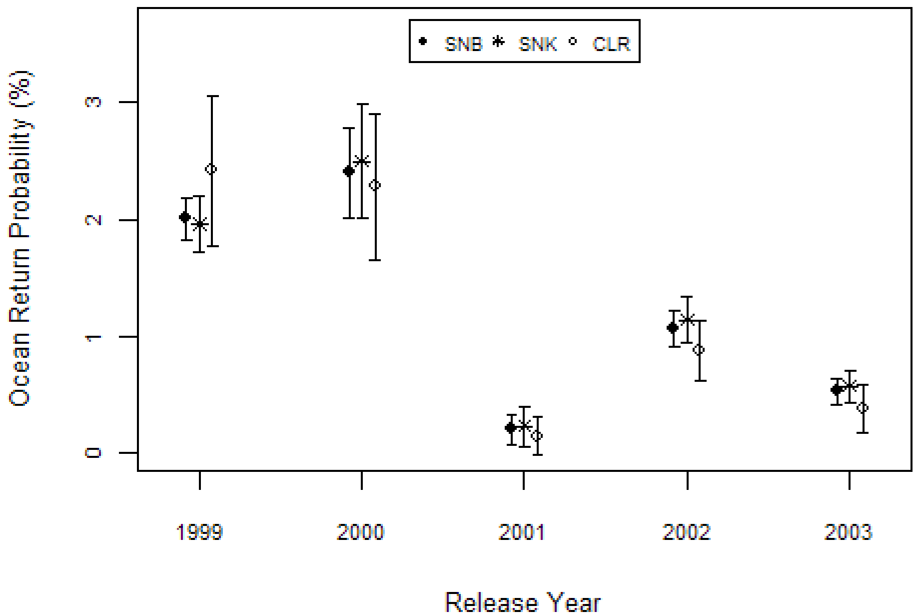


Figure 4.9: Estimated ocean return probability (to Bonneville) for nontransported spring Chinook salmon ($\widehat{O_{NT}}$), with 95% confidence intervals. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater.

Snake River Basin (release area SNB; Figure 4.10; Table G.5) ranged from 0.60% ($\widehat{SE} = 0.04\%$) for the 2003 release group to 3.15% ($\widehat{SE} = 0.12\%$) for the 2000 release group, with an average of 1.81% ($\widehat{SE} = 0.54\%$) for the release years 1999 to 2003. Estimates of O_{LGR} for hatchery Clearwater spring Chinook were unavailable for the 1999 and 2002 release years because too few (i.e., $< 5,000$) tagged Clearwater fish were transported from Lower Granite in those years. For the release years 2000, 2001, and 2003, estimates of O_{LGR} for Clearwater spring Chinook ranged from 0.40% ($\widehat{SE} = 0.08\%$) for the 2003 release year to 2.09% ($\widehat{SE} = 0.15\%$) for the 2000 release year, with an average of 0.98% ($\widehat{SE} = 0.55\%$). Estimates of the ocean return probability for LGR-transport spring Chinook from the Snake River (release area SNK) were available for each year from 1999 to 2003, ranging from 0.63% ($\widehat{SE} = 0.04\%$) in 2003 to 3.91% ($\widehat{SE} = 0.17\%$) in 2000, with an average of 2.11% ($\widehat{SE} = 0.62\%$) over those years. These estimates do not include jacks; results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

Estimates of the ocean return probability for LGS-transport spring Chinook from the Snake River Basin (release area SNB; Figure 4.11; Table G.6) ranged from 0.45% ($\widehat{SE} = 0.05\%$) for the 2003 release group to 3.04% ($\widehat{SE} = 0.22\%$) for the 1999 release group, with an average of 1.48% ($\widehat{SE} = 0.52\%$) for release years 1999 to 2003. Transportation from Little Goose could be analyzed

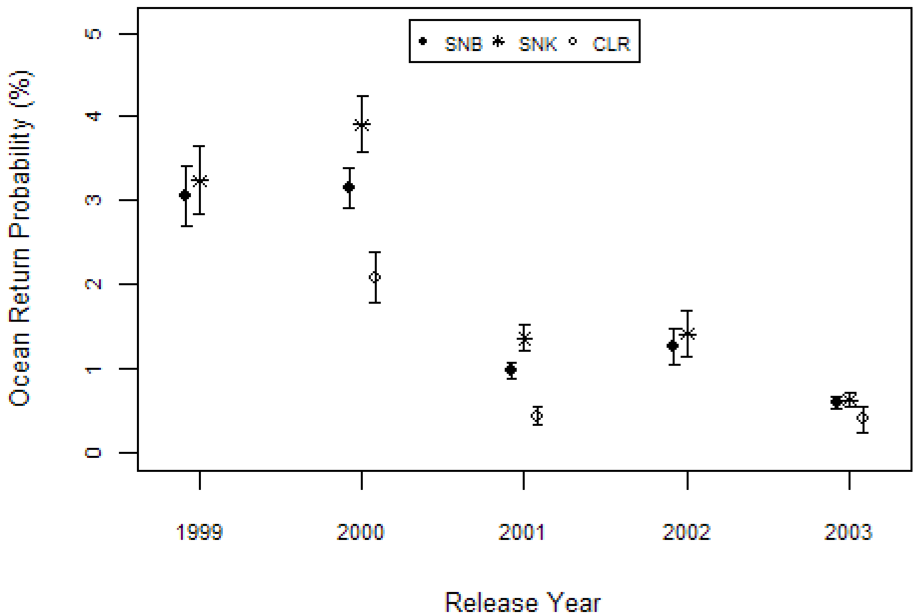


Figure 4.10: Estimated ocean return probability for LGR-transported spring Chinook salmon ($\widehat{O_{LGR}}$), with 95% confidence intervals. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable in 1999 and 2002 because too few tagged Clearwater spring Chinook were transported from LGR to analyze an LGR-transport group for those years.

for hatchery Clearwater spring Chinook only for the 2000 release group, when the ocean return probability was estimated at $\widehat{O_{LGS}} = 1.69\%$ ($\widehat{SE} = 0.18\%$). For hatchery spring Chinook from the Snake River (release area SNK), estimates of the ocean return probability for LGS-transport fish ranged from 0.45% ($\widehat{SE} = 0.05\%$) in 2003 to 3.42% ($\widehat{SE} = 0.27\%$) in 1999, with an average of 1.68% ($\widehat{SE} = 0.62\%$) for release years 1999 to 2003. These estimates do not include jacks. Estimates of O_{LGS} including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

A paired t-test found no indication that LGR-transport fish had lower ocean return probabilities than nontransported fish for either Clearwater (t_2=0.9290, P=0.7745) or Snake River (SNK; t_4=2.0227, P=0.9434) fish, or for the Snake River Basin fish (SNB; t_4=1.9042, P=0.9352). Similarly, there was no indication that LGS-transport fish had lower ocean return probabilities than nontransported fish for Snake River fish (SNK; t_4=1.2135, P=0.8542) or for the larger Snake River Basin group (SNB; t_4=1.1313, P=0.8394).

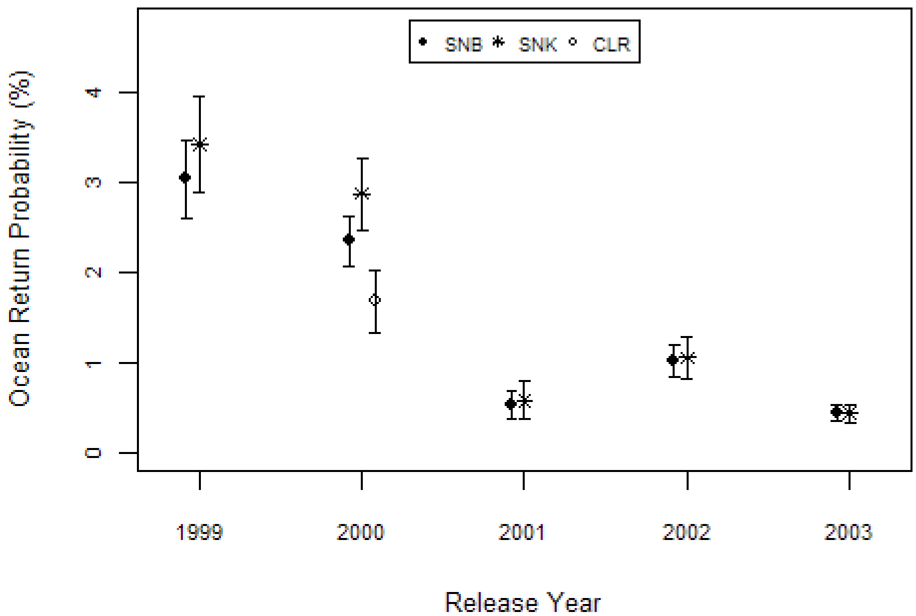


Figure 4.11: Estimated ocean return probability for LGS-transported spring Chinook salmon ($\widehat{O_{LGS}}$), with 95% confidence intervals. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were available only in 2000 because too few tagged Clearwater spring Chinook were transported at LGS to analyze an LGS-transport group in other years.

4.3.2 Hatchery Summer Chinook Salmon

Estimated values of the ocean return probability (O_{NT}) for nontransported hatchery summer Chinook salmon (Figure 4.12; Table G.4) were highest for the 1999 release group ($\widehat{O_{NT}} = 4.73\%$, $\widehat{SE} = 0.43\%$) and lowest for the 2003 release group ($\widehat{O_{NT}} = 0.81\%$, $\widehat{SE} = 0.12\%$). Too few adult detections of nontransported summer Chinook from the 2001 release year made estimation of O_{NT} for 2001 impossible, but results for spring Chinook and estimates of SAR for summer Chinook (Figure 4.3) suggest that O_{NT} was very low for the 2001 release group. The mean estimate of the nontransported ocean return probability for summer Chinook for release years 1999, 2000, 2002, and 2003 was 2.77% ($\widehat{SE} = 0.90\%$). These estimates of O_{NT} do not include jacks; results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

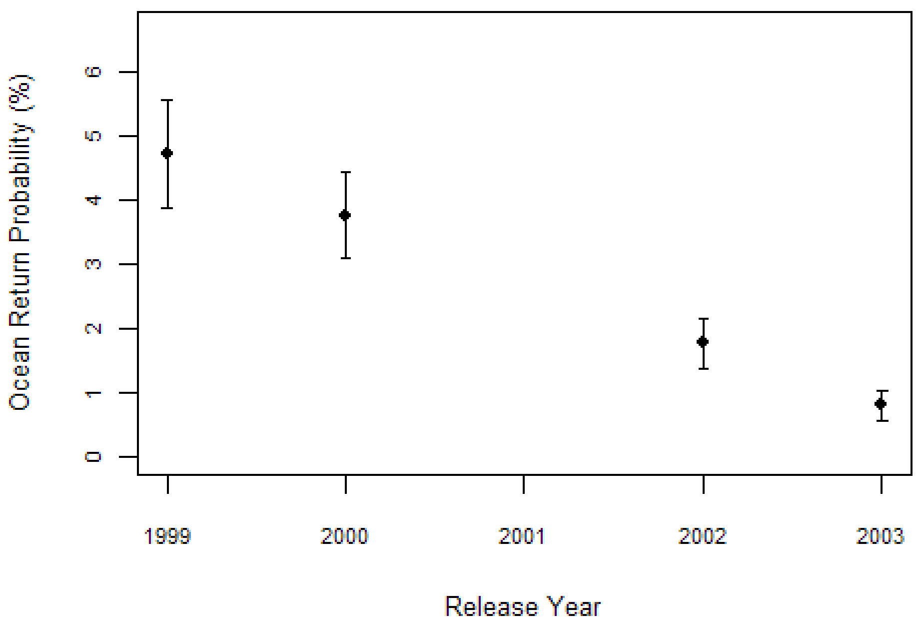


Figure 4.12: Estimated ocean return probability for nontransported summer Chinook salmon ($\widehat{O_{NT}}$), with 95% confidence intervals. Estimates do not include jacks. Estimates were not calculated for 2001 because there were too few adult detections of nontransported fish from the 2001 release group.

Enough (i.e., $\geq 5,000$) tagged hatchery summer Chinook were transported at Lower Granite in release years 2000, 2001, and 2003 to analyze LGR-transport groups for those years. However, too few nontransported fish from the 2001 release group were detected as adults to making fitting the full ROSTER model possible for the 2001 release year, and so it was impossible to estimate the ocean return probability for LGR-transport summer Chinook (O_{LGR}) for 2001. The estimated ocean return probability for LGR-transport fish was 5.45% ($\widehat{SE} = 0.25\%$) for the 2000 release group, and 0.99% ($\widehat{SE}$ = 0.10%) for the 2003 release group, with an average of 3.22% ($\widehat{SE}$ = 2.23%) over those two years (Figure 4.13; Table G.5). The only release year with at least 5,000 tagged summer Chinook transported at Little Goose was 1999, when the ocean return probability for the LGS-transport group was estimated at $\widehat{O_{LGS}}$ = 4.03% ($\widehat{SE}$ = 0.31%; Table G.6). These estimates do not include jacks; results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

With both point estimates of O_{LGR} greater than analogous point estimates for nontransported fish ($\widehat{O_{NT}}$), there is no evidence that transportation at LGR lowered ocean survival for hatchery summer Chinook salmon. The single point estimate of O_{LGS} (for 1999) is significantly smaller than the analogous point estimate for nontransported fish, based on a one-sided z-test (z=-1.3758, $P = 0.0844$).

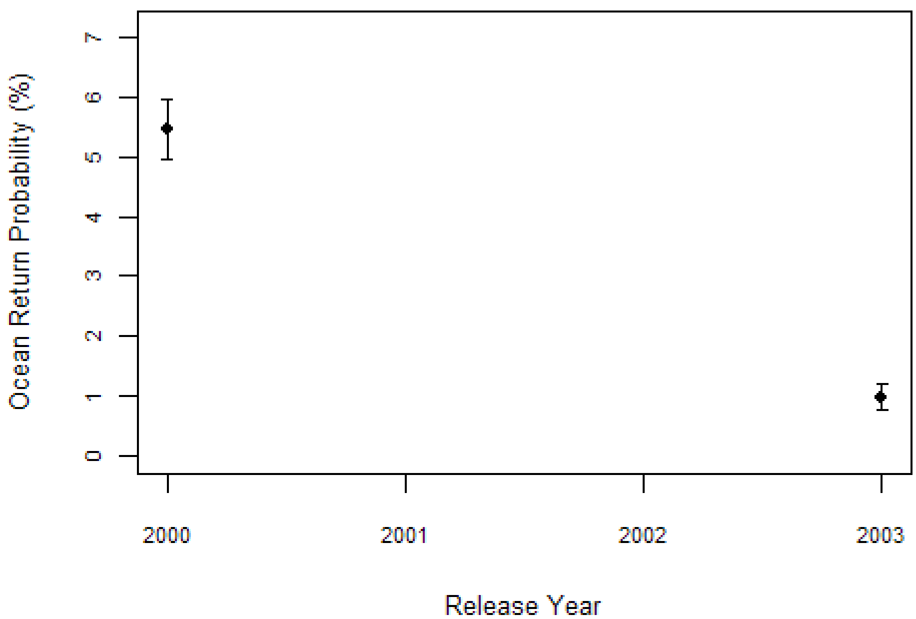


Figure 4.13: Estimated ocean return probability for LGR-transport summer Chinook ($\widehat{O_{LGR}}$), with 95% confidence intervals. Estimates do not include jacks. Estimates were unavailable in 1999 and 2002 because too few tagged summer Chinook were transported to analyze an LGR-transport group for those years. An estimate was unavailable for the 2001 release group because too few adult detections of nontransported fish made it impossible to fit the full ROSTER model.

4.3.3 Hatchery Steelhead

Estimates of the ocean return probability for nontransported hatchery steelhead from the Snake River Basin (O_{NT}; Figure 4.14; Table G.4) ranged from 1.67% ($\widehat{SE} = 0.29\%$) for the 1999 release group to 5.28% ($\widehat{SE} = 0.63\%$) for the 2000 release group. Too few adult detections of tagged steelhead from the 2001 release group made it impossible to estimate the ocean return probability for 2001, but the estimate of SAR for 2001 steelhead (Figure 4.5) suggests that O_{NT} is very low for 2001 steelhead. The average estimated ocean return probability for hatchery steelhead for release years 1999, 2000, 2002, and 2003 was 2.80% ($\widehat{SE} = 0.87\%$). The estimates include age-1-ocean fish. Because no steelhead transport groups were analyzed, no estimates of O_{LGR} or O_{LGS} are available for hatchery steelhead.

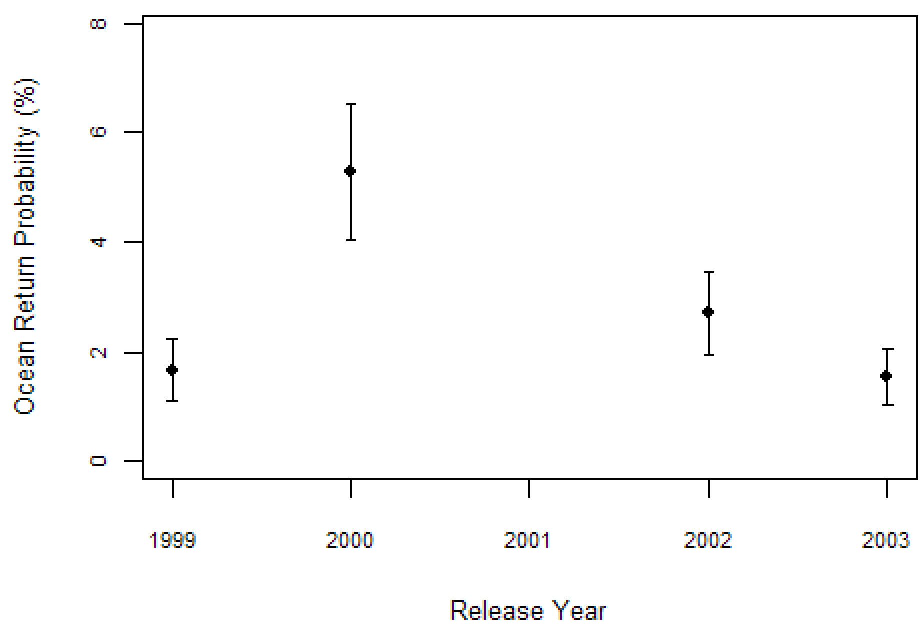


Figure 4.14: Estimated ocean return probability for nontransported steelhead ($\widehat{O_{NT}}$), with 95% confidence intervals. Estimates include the age-1-ocean age class. Estimates were not calculated in 2001 because there were too few adults detected from that release group to fit the full ROSTER model.

4.4 Adult Upriver Survival

Average perceived adult upriver survival ("adult upriver survival") from Bonneville to Lower Granite was estimated both on a release group basis ($S_{A_{Release}}$, abbreviated $S_{A_{Rel}}$), and also for all tagged adults present in a given calendar year or return year ($S_{A_{Return}}$, abbreviated $S_{A_{Ret}}$). The two measures are useful for different purposes. Adult upriver survival by release group, $S_{A_{Rel}}$, is a component of SAR for a given release group or brood year, and is helpful in determining the relative contributions of the different migratory stages to overall mortality (see Section 2.2.4). Additionally, $S_{A_{Rel}}$ is useful for relating adult upriver survival to juvenile migration experience, such as transportation. Adult upriver survival by return year, $S_{A_{Ret}}$, is useful for assessing the effects of annual operations and river environment directly on migrating adults. It gives a snapshot of the state of the river in a given calendar year. The two measures $S_{A_{Rel}}$ and $S_{A_{Ret}}$ are complementary, providing estimates of adult upriver survival through the hydrosystem from two alternative viewpoints. Both measures represent "perceived" survival because their complements include both straying and harvest, in addition to natural mortality.

Both $S_{A_{Rel}}$ and $S_{A_{Ret}}$ are estimated using data from both transported and nontransported fish. Adult upriver survival by release group is further estimated separately for nontransported fish ($S_{A_{NT}}$), LGR-transport fish ($S_{A_{LGR}}$), and LGS-transport fish ($S_{A_{LGS}}$). Inference from all estimates of adult upriver survival is to the tagged fish in the release groups. For Chinook, estimates of $S_{A_{Rel}}$, $S_{A_{NT}}$, $S_{A_{LGR}}$, $S_{A_{LGS}}$, and $S_{A_{Ret}}$ represent average adult upriver survival for non-jack adults, while steelhead estimates include age-1-ocean adults. Additional results including jacks for Chinook and excluding age-1-ocean adults for steelhead are available online at `http://www.cbr.washington.edu/trends/roster.php`. Estimates that combine transported and nontransported fish (i.e., $S_{A_{Rel}}$ and $S_{A_{Ret}}$) or that are restricted to nontransported fish (i.e., $S_{A_{NT}}$) are available for all release groups after 1998, when adult detections at Bonneville were available. Estimates that are restricted to transport fish (i.e., $S_{A_{LGR}}$ and $S_{A_{LGS}}$) are available only for release groups with transport groups of at least 5,000 fish. Estimates of adult upriver survival for transport fish are not available for transport groups that were censored because of low numbers. Thus, some Chinook release groups and all steelhead release groups are missing estimates for $S_{A_{LGR}}$ and $S_{A_{LGS}}$.

4.4.1 Hatchery Spring Chinook Salmon

Estimates of perceived adult upriver survival by release group ($S_{A_{Rel}}$) for hatchery spring Chinook salmon from the Snake River Basin (release area SNB; Figure 4.15; Table G.7) ranged from 75.3% ($\widehat{SE}$ = 1.0%) for the 2000 release group to 83.0% ($\widehat{SE}$ = 1.0%) for the 2002 release group, with an average of 78.6% ($\widehat{SE}$ = 1.4%) for the release years 1999 to 2003. Estimates of $S_{A_{Rel}}$ for hatchery Clearwater spring Chinook were highest for the 2002 release group ($\widehat{S_{A_{Rel}}}$ = 87.1%, $\widehat{SE}$ = 2.3%) and lowest for the 2000 release group ($\widehat{S_{A_{Rel}}}$ = 68.5%, $\widehat{SE}$ = 2.0%), with an average of 78.5% ($\widehat{SE}$ = 3.0%) over the release years 1999 to 2003. For Snake River hatchery spring Chinook (release area SNK), estimates of adult upriver survival by release group were highest for the 2002 release group ($\widehat{S_{A_{Rel}}} = 83.0\%$, $\widehat{SE} = 1.1\%$) and lowest for the 2001 release ($\widehat{S_{A_{Rel}}} = 76.1\%$, $\widehat{SE} = 2.3\%$), with an average of 79.6% ($\widehat{SE} = 1.2\%$) over the release years 1999 to 2003.

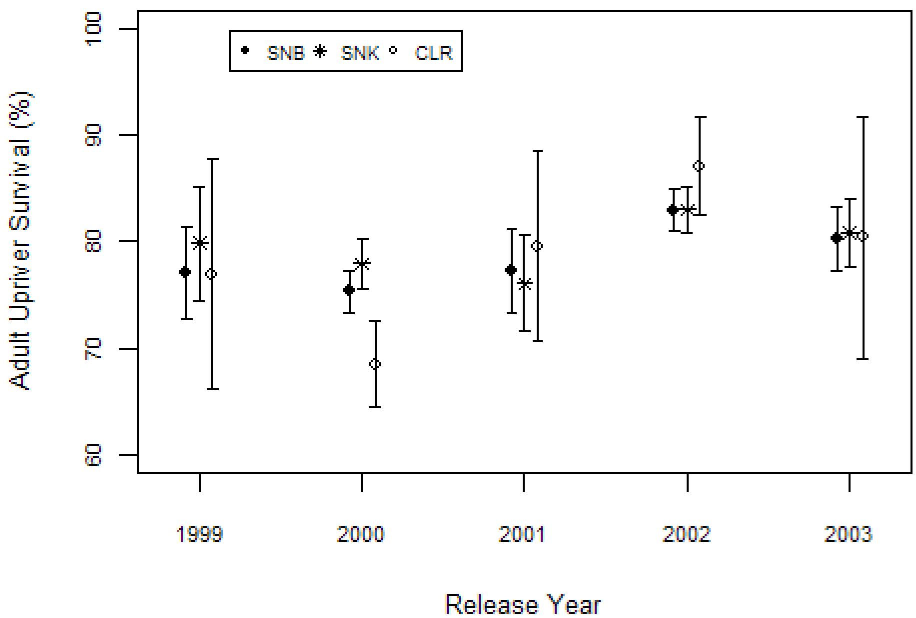


Figure 4.15: Estimated perceived adult upriver survival by release group ($\widehat{S_{A_{Rel}}}$) for spring Chinook salmon, with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from both transported and nontransported fish, and do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater.

When restricted to nontransported fish, estimates of adult upriver survival by release group for SNB spring Chinook (Figure 4.16; Table G.8) were highest for the 2003 release group ($\widehat{S_{A_{NT}}} = 84.3\%$, $\widehat{SE} = 1.9\%$), lowest for the 2001 release group ($\widehat{S_{A_{NT}}} = 77.1\%$, $\widehat{SE} = 2.0\%$), and averaged 81.5% ($\widehat{SE} = 1.4\%$) for release years 1999 to 2003. Estimates of adult upriver survival by release group for nontransported Clearwater spring Chinook ranged from 68.5% ($\widehat{SE} = 2.0\%$) for the 2000 release group to 87.4% ($\widehat{SE} = 10.8\%$) for the 2001 release group, with an average of 80.6% ($\widehat{SE} = 3.6\%$) for the release years from 1999 to 2003. The estimates of adult upriver survival by release group for nontransported SNK spring Chinook were highest for the 2000 release group ($\widehat{S_{A_{NT}}} = 85.0\%$, $\widehat{SE} = 1.6\%$), lowest for the 2001 release group ($\widehat{S_{A_{NT}}} = 76.0\%$, $\widehat{SE} = 2.3\%$), and averaged 82.0% ($\widehat{SE} = 1.6\%$) for the release years 1999 to 2003.

Estimated adult upriver survival for LGR-transport spring Chinook from the Snake River Basin (release area SNB; Figure 4.17; Table G.9) was highest for the 2001 ($\widehat{S_{A_{LGR}}} = 77.2\%$, $\widehat{SE} = 2.0\%$) and the 2002 ($\widehat{S_{A_{LGR}}} = 77.2\%$, $\widehat{SE} = 2.6\%$) release groups, lowest for the 2000 release group

($\widehat{S_{A_{LGR}}}$ = 69.0%, $\widehat{SE}$ = 1.5%), and averaged 74.5% ($\widehat{SE}$ = 1.6%) for the release years 1999 to 2003. A paired t-test indicated that overall adult upriver survival from Bonneville to Lower Granite was significantly lower for LGR-transport SNB spring Chinook than for nontransported SNB spring Chinook ($t_4 = -3.2071$, $P = 0.0163$). Estimated adult upriver survival for SNB spring Chinook transported at Little Goose (Figure 4.18; Table G.10) was highest for the 2001 release group ($\widehat{S_{A_{LGS}}}$ = 77.3%, $\widehat{SE}$ = 2.0%), lowest for the 2000 release group ($\widehat{S_{A_{LGS}}}$ = 69.0%, $\widehat{SE}$ = 1.5%), and averaged 74.6% ($\widehat{SE}$ = 1.6%) for release years 1999 to 2003. A paired t-test indicated that overall adult upriver survival from Bonneville to Lower Granite for SNB spring Chinook was significantly lower for LGS-transport fish than for nontransport fish ($t_4 = -3.1529$, $P = 0.0172$). There was no detectable difference between adult upriver survival for LGR-transport fish and LGS-transport fish for SNB spring Chinook.

Estimates of adult upriver survival for LGR-transport groups of Clearwater spring Chinook were available only for the 2000, 2001, and 2003 release groups; there were too few ($< 5,000$) tagged Clearwater spring Chinook transported from Lower Granite in 1999 and 2002 to analyze LGR-transport groups for those years. Among the three release years with estimates, the highest estimated value of $\widehat{S_{A_{LGR}}}$ for Clearwater fish was for the 2001 release group ($\widehat{S_{A_{LGR}}}$ = 78.2%, $\widehat{SE}$ = 5.0%), the lowest estimated value was for the 2000 release group ($\widehat{S_{A_{LGR}}}$ = 73.2%, $\widehat{SE}$ = 2.1%), and the average estimated value was 73.2% ($\widehat{SE}$ = 2.8%; Figure 4.17; Table G.9). This average $\widehat{S_{A_{LGR}}}$ was lower than the average adult upriver survival estimate for nontransported fish (81%). A paired t-test indicated that LGR-transport fish had significantly lower adult upriver survival (from Bonneville to Lower Granite) than nontransported fish for the Clearwater releases in 2000, 2001, and 2003 ($t_2 = -1.9840$, $P = 0.0928$). Only the 2000 release group had enough ($\geq 5,000$) tagged Clearwater spring Chinook transported at Little Goose to analyze an LGS-transport group (Figure 4.18; Table G.10). For the 2000 Clearwater spring Chinook transported at Little Goose, the estimated adult upriver survival was $\widehat{S_{A_{LGS}}}$ = 68.6% ($\widehat{SE}$ = 2.1%), which was equal to the estimate for nontransported Clearwater Chinook from the 2000 release (Table G.8).

Snake River spring Chinook (release area SNK) had estimates of adult upriver survival for LGR-transport fish for all release years from 1999 to 2003 (Figure 4.17; Table G.9). The highest estimate of $S_{A_{LGR}}$ was 79.8% ($\widehat{SE}$ = 2.9%) for the 2002 release group, the lowest estimate was 71.9% ($\widehat{SE}$ = 1.7%) for the 2000 release group, and the average estimate for release years 1999 to 2003 was 76.6% ($\widehat{SE}$ = 1.3%). A paired t-test indicated that overall adult upriver survival from Bonneville to Lower Granite for the SNK releases was significantly lower for LGR-transport fish than for nontransported fish from 1999 to 2003 ($t_4 = -2.3987$, $P = 0.0372$). Estimates of adult upriver survival for LGS-transport fish from the SNK releases (Figure 4.18; Table G.10) ranged from 71.9% ($\widehat{SE}$ = 1.7%) for the 2000 release group to 79.8% ($\widehat{SE}$ = 2.9%) for the 2002 release group, with an average estimate of 76.9% ($\widehat{SE}$ = 1.4%) over release years 1999 to 2003. There was no detectable difference in adult upriver survival between the LGR and LGS transport groups for SNK fish. A paired t-test indicated that nontransported fish from the SNK releases had higher adult upriver survival (from Bonneville to Lower Granite) than LGS-transport fish ($t_4 = -2.3028$, $P = 0.0413$).

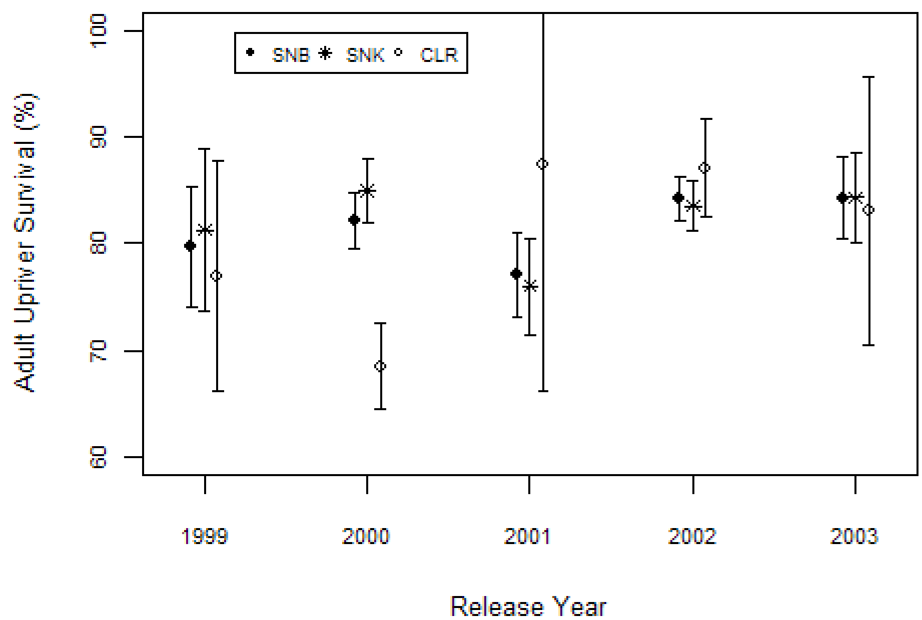


Figure 4.16: Estimated perceived adult upriver survival by release group for nontransported spring Chinook salmon ($\widehat{S_{A_{NT}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from nontransported fish, and do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater.

Adult upriver survival was also estimated for all hatchery spring Chinook adults present in the hydrosystem in a given return (or calendar) year. This measure, $S_{A_{Ret}}$, combines estimates from multiple release years, and incorporates data from both transported and nontransported fish. The measure $S_{A_{Ret}}$ gives an indication of river conditions in a given calendar year, as reflected in adult upriver survival. For spring Chinook, estimates are available for return years 2001 through 2006, based on releases from 1999 through 2003. Jacks are not included in the results presented here; results including jacks are available at `http://www.cbr.washington.edu/trends/roster.php`. For spring Chinook from the Snake River Basin (release area SNB; Figure 4.19; Table G.11), estimates of $S_{A_{Ret}}$ ranged from 70.8% ($\widehat{SE} = 5.9\%$) in 2006 to 83.1% ($\widehat{SE} = 0.97\%$) in 2004, with an average of 77.2% ($\widehat{SE} = 1.8\%$) from 2001 to 2006. For Clearwater spring Chinook, estimates of $S_{A_{Ret}}$ ranged from 65.8% ($\widehat{SE} = 3.2\%$) in 2002 to 86.9% ($\widehat{SE} = 2.3\%$) in 2004, with an average estimate of 76.6% ($\widehat{SE} = 2.9\%$) from 2001 to 2006. For Snake River spring Chinook (release area SNK), estimates of $S_{A_{Ret}}$ ranged from 69.3% ($\widehat{SE} = 7.1\%$) in 2006 to 83.2% ($\widehat{SE} = 1.1\%$) in 2004, with an average estimate of 78.1% ($\widehat{SE} = 2.0\%$) from 2001 to 2006.

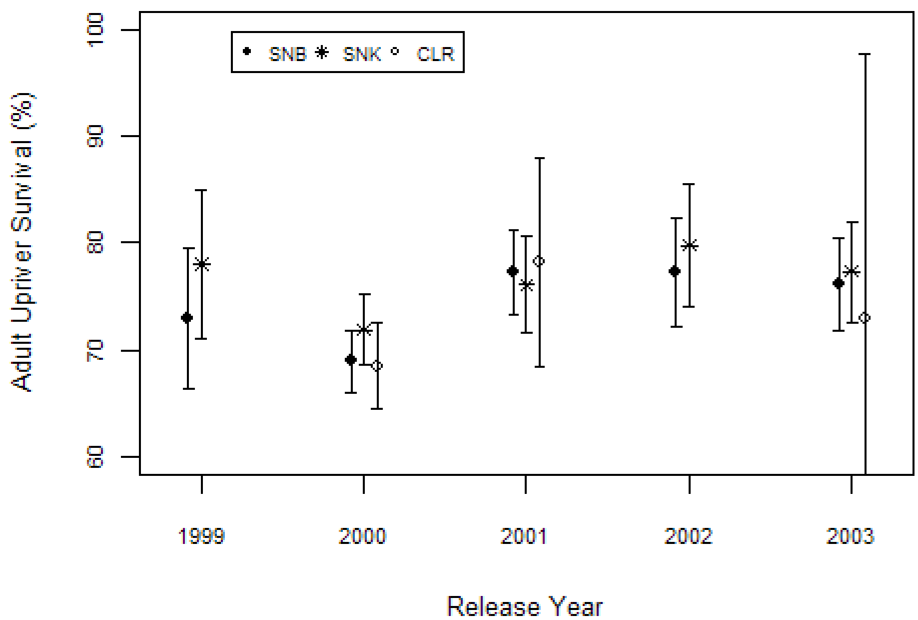


Figure 4.17: Estimated perceived adult upriver survival by release group for LGR-transport spring Chinook salmon ($\widehat{S_{A_{LGR}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from LGR-transport fish, and do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable in 1999 and 2000 because too few ($< 5,000$) tagged Clearwater smolts were transported at Lower Granite to analyze LGR-transport groups in those years.

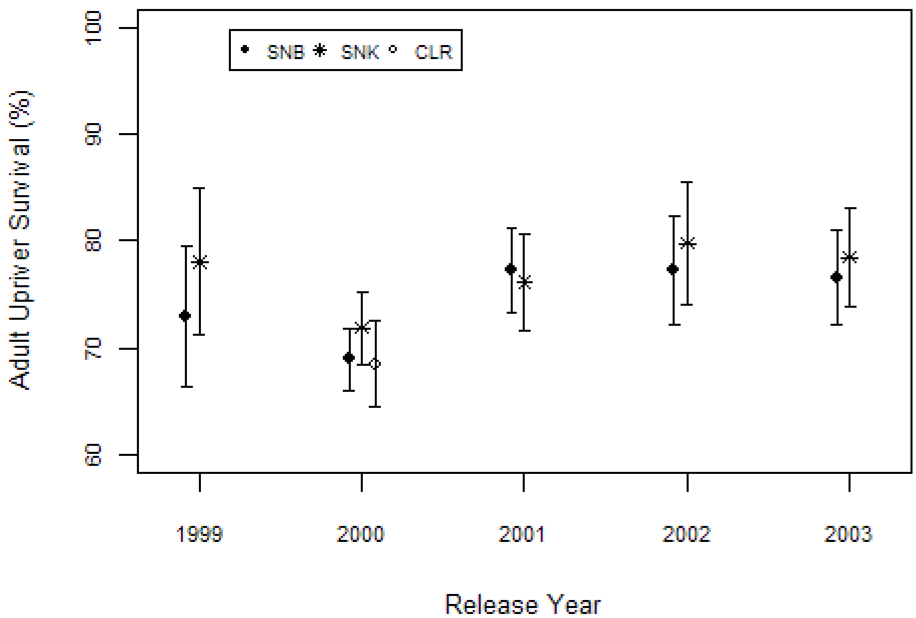


Figure 4.18: Estimated perceived adult upriver survival by release group for LGS-transport spring Chinook salmon ($\widehat{S_{A_{LGS}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from LGS-transport fish, and do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were available only in 2000 because too few ($< 5,000$) tagged Clearwater smolts were transported at Little Goose to analyze LGR-transport groups in other years.

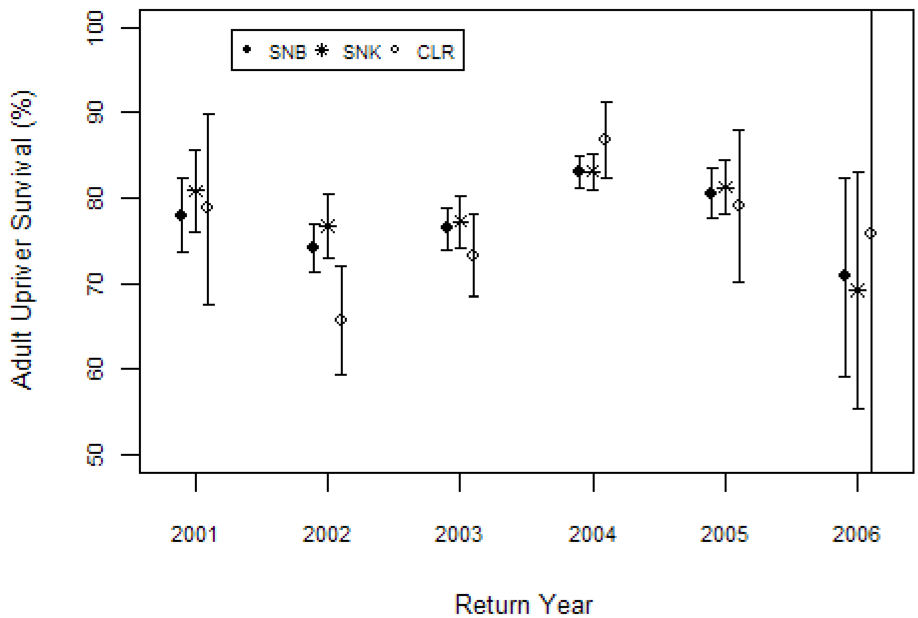


Figure 4.19: Estimated perceived adult upriver survival by return group ($\widehat{S_{A_{Ret}}}$) for spring Chinook salmon, with 95% confidence intervals. Estimates incorporate adult detections from multiple release years, and from both transported and nontransported fish. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater.

4.4.2 Hatchery Summer Chinook Salmon

Estimates of average adult upriver survival from Bonneville to Lower Granite for a given release group ($S_{A_{Rel}}$) for hatchery summer Chinook (Figure 4.20; Table G.7) ranged from 80.6% ($\widehat{SE} = 2.3\%$) for the 2002 release group to 86.5% ($\widehat{SE} = 1.1\%$) for the 2000 release group. The estimate for 2001 is a heuristic estimate (see Appendix E.5) produced outside the full ROSTER model; there were too few adult detections of nontransported summer Chinook from the 2001 release group to fit the full ROSTER model for that year. The average estimate of adult upriver survival by release group from 1999 to 2003 was 83.4% ($\widehat{SE} = 1.1\%$) for hatchery summer Chinook. These estimates incorporate both transported and nontransported fish, and do not include jacks. Estimates including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

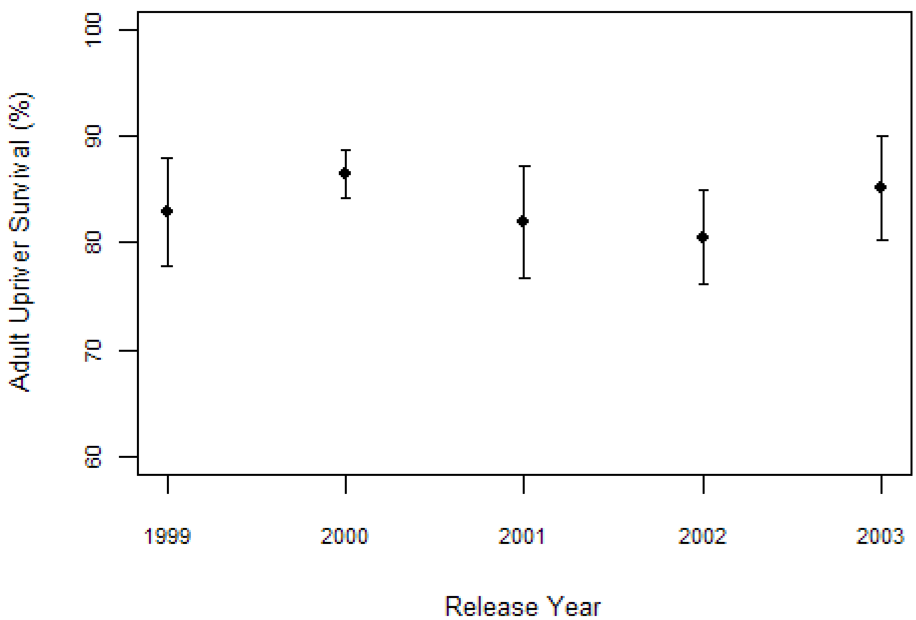


Figure 4.20: Estimated perceived adult upriver survival by release group ($\widehat{S_{A_{Rel}}}$) for summer Chinook salmon, with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from both transported and nontransported fish, and do not include jacks. The estimate for the 2001 release group is a heuristic estimate produced outside the full ROSTER model.

When restricted to nontransported fish, estimates of adult upriver survival by release group ($S_{A_{NT}}$) for hatchery summer Chinook (Figure 4.21; Table G.8) ranged from 80.6% ($\widehat{SE} = 2.3\%$) for the 2002 release (when no summer Chinook transport group was analyzed) to 90.0% ($\widehat{SE} = 9.5\%$) for the 2001 release group. The 2001 estimate is a heuristic estimate (see Appendix E.5) produced outside the full ROSTER model. The average estimate of adult upriver survival for nontransported summer Chinook was 85.0% ($\widehat{SE} = 1.6$) for release groups from 1999 to 2003.

There were too few ($< 5,000$) tagged hatchery summer Chinook transported at Lower Granite in 1999 and 2002 to analyze LGR-transport groups for those years, so estimates of adult upriver survival for LGR-transport fish ($S_{A_{LGR}}$) are available only for the 2000, 2001, and 2003 release groups for hatchery summer Chinook (Figure 4.22; Table G.9). The 2001 estimate of $S_{A_{LGR}}$ is a heuristic estimate (Appendix E.5) because the low number of nontransported adult detections from 2001 made it impossible to fit the full ROSTER model for that release year. For the three years with estimates of $S_{A_{LGR}}$ for hatchery summer Chinook, the highest estimate was 86.9% ($\widehat{SE} = 1.1\%$) for the 2000 release group, the lowest estimate was 81.5% ($\widehat{SE} = 2.8\%$) for the 2001 release group, and the average estimate was 84.2% ($\widehat{SE} = 1.5\%$). A paired t-test failed to show that LGR-transport summer Chinook had significantly lower adult upriver survival than nontransported fish (t_2=-1.1082, P=0.1916).

Only a single release year (1999) had enough tagged hatchery summer Chinook transported at Little Goose to analyze an LGS-transport group. The estimate of adult upriver survival for the 1999 LGS-transport group was 82.8% ($\widehat{SE} = 2.6\%$, Table G.10) for hatchery summer Chinook. This estimate was equal to the analogous estimate for nontransported summer Chinook for 1999 (Table G.8).

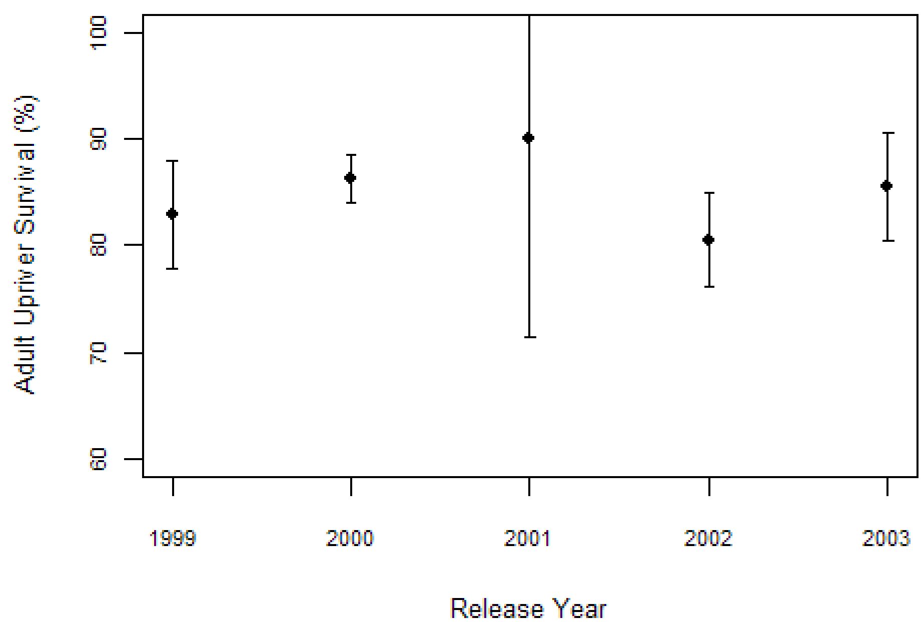


Figure 4.21: Estimated perceived adult upriver survival by release group for nontransported summer Chinook salmon ($\widehat{S_{A_{NT}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from nontransported fish, and do not include jacks. The estimate for the 2001 release year is a heuristic estimate produced outside the full ROSTER model.

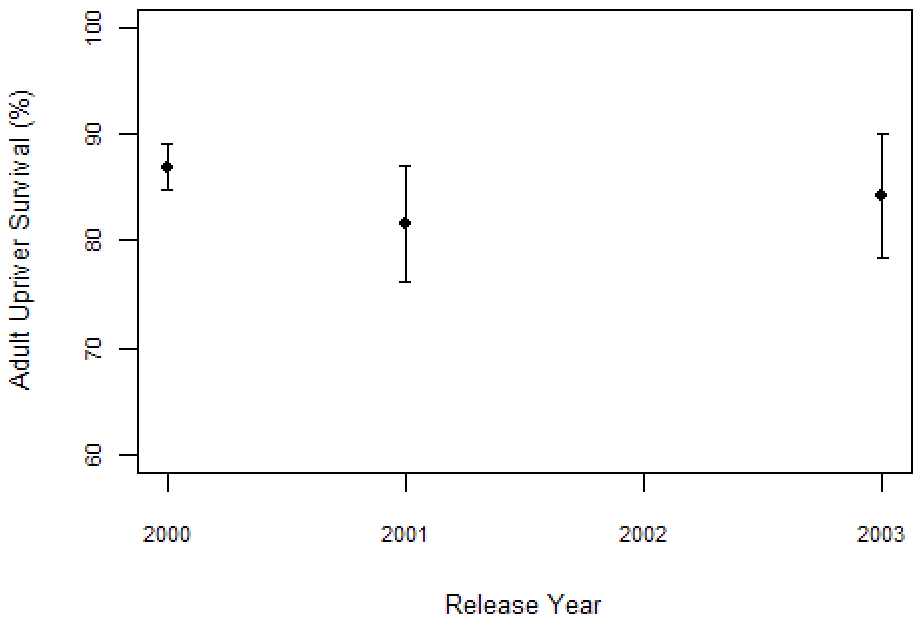


Figure 4.22: Estimated perceived adult upriver survival by release group for LGR-transport summer Chinook salmon ($\widehat{S_{A_{LGR}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from LGR-transport fish, and do not include jacks. Estimates were unavailable in 1999 and 2002 because too few tagged hatchery summer Chinook were transported at Lower Granite to analyze LGR-transport groups in those years. The estimate for the 2001 release group is a heuristic estimate produced outside the full ROSTER model.

Adult upriver survival by return year ($S_{A_{Ret}}$) combines results from multiple release years, and incorporates detections from both transported and nontransported fish. Estimates of $S_{A_{Ret}}$ are available for return years 2001 through 2006 for hatchery summer Chinook. Because estimates of $S_{A_{Ret}}$ depend on estimated age-specific adult upriver survival estimates from previous release groups, the estimates of $S_{A_{Ret}}$ for return years 2003 and 2004 both use the heuristic estimates of age-specific adult upriver survival from the 2001 release group. Estimates of $S_{A_{Ret}}$ for hatchery summer Chinook ranged from 75.0% ($\widehat{SE} = 8.4\%$) in 2006 to 88.5% ($\widehat{SE} = 1.4\%$) in 2002. The average estimated adult upriver survival by return year for hatchery summer Chinook was 82.3% ($\widehat{SE} = 2.1\%$) from 2001 to 2006. These estimates do not include jacks; resulting including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

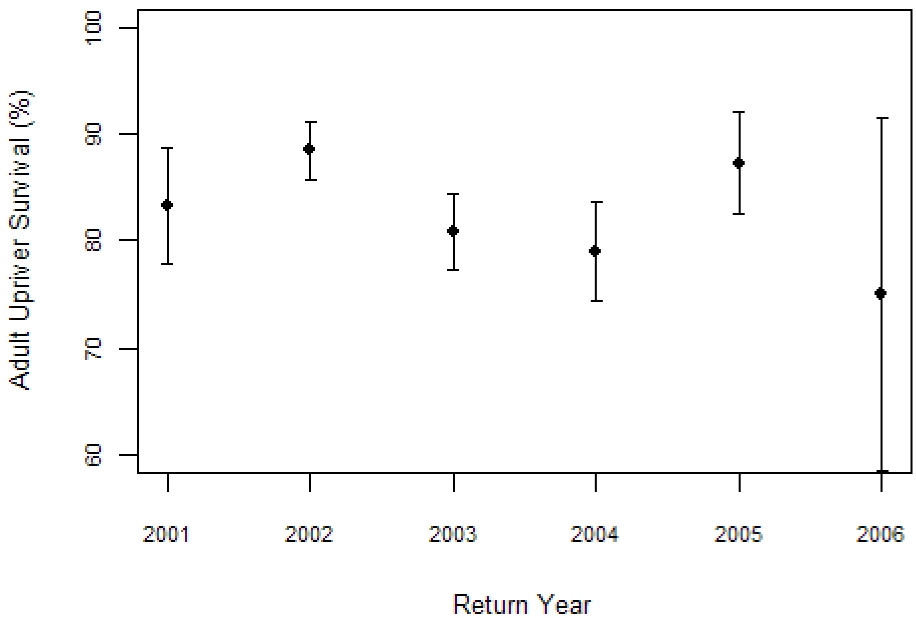


Figure 4.23: Estimated perceived adult upriver survival by return year for summer Chinook ($\widehat{S_{A_{Ret}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple release years, and from both transported and nontransported fish. Estimates do not include jacks. The estimates for return years 2003 and 2004 are partially based on a heuristic (i.e., non-ROSTER model) analysis of the 2001 release group.

4.4.3 Hatchery Steelhead

Estimates of average adult upriver survival by release group ($S_{A_{Rel}}$) for hatchery steelhead (Figure 4.24; Table G.7) ranged from 45.8% ($\widehat{SE}$ = 15.1%) for the 2001 release group to 85.2% ($\widehat{SE} = 2.9\%$) for the 2002 release group. The average estimate of $S_{A_{Rel}}$ for hatchery steelhead was 72.5% ($\widehat{SE}$ = 6.9%) for release years 1999 to 2003. These estimates include the age-1-ocean age class. Because no steelhead transport groups were analyzed, $S_{A_{Rel}}$ reflects only nontransported fish for steelhead (i.e., $S_{A_{Rel}} = S_{A_{NT}}$). The estimate of $S_{A_{Rel}}$ for the 2001 release group is a heuristic estimate, produced outside the full ROSTER model. It was necessary to use heuristic analysis methods for 2001 because the very low numbers of adult detections from the 2001 release group prevented the ROSTER model from fitting for that data set. The low numbers of adult detections from the 2001 release group are reflected in the wide confidence intervals for the 2001 estimate of $S_{A_{Rel}}$.

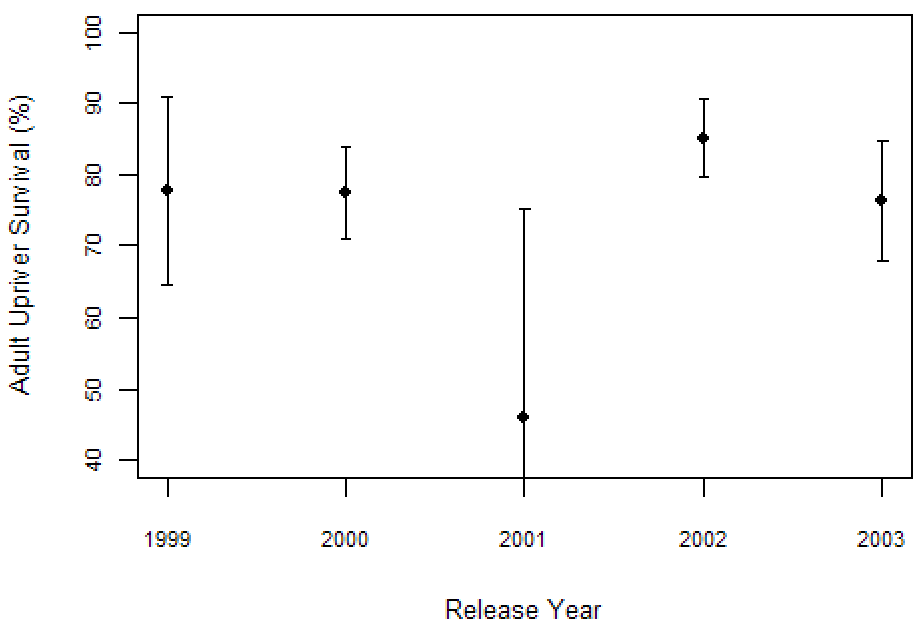


Figure 4.24: Estimated perceived adult upriver survival by release group for steelhead ($\widehat{S_{A_{Rel}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple return years from nontransported fish, and include the age-1-ocean age class. The estimate for the 2001 release group is a heuristic estimate, produced outside the full ROSTER model.

The adult upriver survival by return year ($S_{A_{Ret}}$) combines estimates from multiple release years to estimate the survival from Bonneville to Lower Granite for all adults present in the hydrosystem in a given return (or calendar) year. Estimates of $S_{A_{Ret}}$ for hatchery steelhead are available for return years 2000 through 2005. Because the 2001 release group was analyzed heuristically (i.e., outside the full ROSTER model), estimates of $S_{A_{Ret}}$ for 2002 and 2003 are partially based on heuristic estimates of age-specific adult upriver survival from the 2001 release group. The highest estimate of adult upriver survival by return year was for 2003 ($\widehat{S_{A_{Ret}}} = 84.9\%$, $\widehat{SE} = 3.3\%$), the lowest estimate was for return year 2000 ($\widehat{S_{A_{Ret}}} = 68.2\%$, $\widehat{SE} = 10.0\%$), and the average estimate was 78.0% ($\widehat{SE} = 2.7\%$) for return years 2000 through 2005.

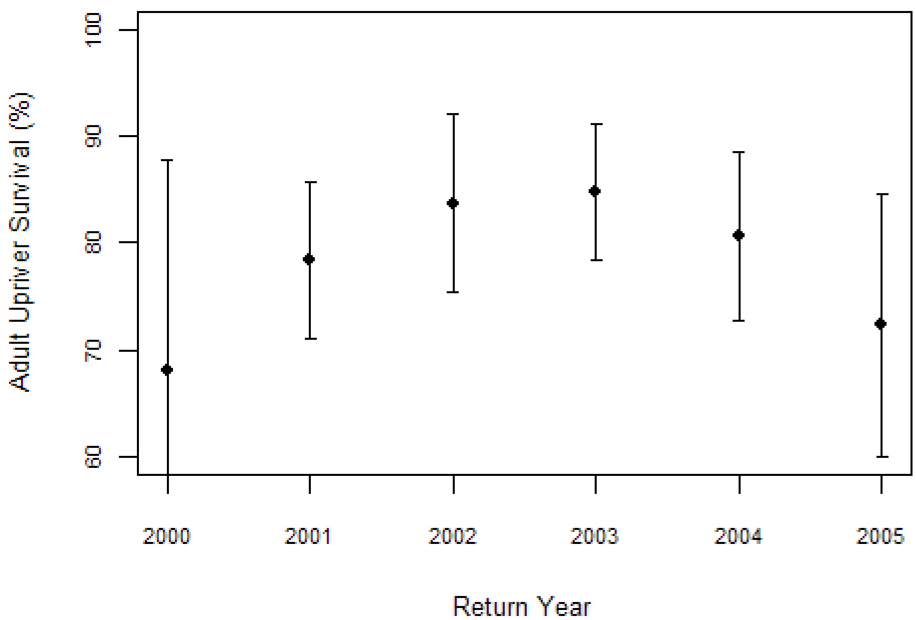


Figure 4.25: Estimated perceived adult upriver survival by return year for steelhead ($\widehat{S_{A_{Ret}}}$), with 95% confidence intervals. Estimates incorporate adult detections from multiple release years from nontransported fish, and include the age-1-ocean age class. Estimates for the 2002 and 2003 return years are partially based on a heuristic (i.e., non-ROSTER model) analysis of the 2001 release group.

4.5 Proportion of Total Integrated Mortality

The total integrated mortality of nontransported fish between passing Lower Granite as a smolt and returning to Lower Granite as an adult was partitioned into juvenile inriver, ocean, and adult upriver components for each release group with estimates of juvenile inriver survival, ocean return probability, and adult upriver survival. Integrated mortality throughout a given life stage incorporates both the instantaneous mortality rate during the life stage and the total time spent during the life stage. Assessing the relative contribution of the three migratory life stages (juvenile inriver, ocean, and adult upriver stages) to total integrated mortality removes confounding of the proportion of all mortality with the order of the life stages. Estimates of proportion of total integrated mortality for Chinook do not include the age-1-ocean age class ("jacks"), while estimates of proportion of total integrated mortality for steelhead do include the age-1-ocean age class.

4.5.1 Hatchery Spring Chinook Salmon

The largest contribution to the total integrated mortality for nontransported spring Chinook salmon from the Snake River Basin (release area SNB) from 1999 to 2003 came from the ocean life stage (Figure 4.26; Tables G.12-G.14). On average, the ocean life stage accounted for approximately $\widehat{\mu_O} = 87\%$ ($\widehat{SE} = 1\%$) of the total integrated mortality between passing LGR as a smolt and returning to LGR as an adult (non-jack). This integrated mortality proportion corresponded to an average ocean return probability of 1.24% ($\widehat{SE} = 0.42\%$) from 1999 to 2003 for nontransported SNB spring Chinook. On average, the juvenile migration from LGR to BON accounted for approximately $\widehat{\mu_J} = 9\%$ ($\widehat{SE} = 1\%$) of the total integrated mortality, corresponding to an average juvenile inriver survival of 61.0% ($\widehat{SE} = 6.9\%$) from 1999 to 2003. The adult migration from BON to LGR accounted for an average of $\widehat{\mu_A} = 4\%$ ($\widehat{SE} = 0.4\%$) of the total integrated mortality from 1999 to 2003, corresponding to an average adult upriver survival of 81.5% ($\widehat{SE} = 1.4\%$) from 1999 to 2003. These estimates do not include jacks.

Similar patterns are seen for nontransported spring Chinook from the Clearwater River (Figure 4.27; Tables G.12-G.14), with approximately $\widehat{\mu_O} = 85\%$ ($\widehat{SE} = 2\%$) of the total integrated mortality accounted for by the ocean life stage on average, $\widehat{\mu_J} = 11\%$ ($\widehat{SE} = 1\%$) accounted for by the juvenile inriver migration, and $\widehat{\mu_A} = 4\%$ ($\widehat{SE} = 1\%$) accounted for by the adult upriver migration. For nontransported Snake River spring Chinook (release area SNK; Figure 4.28), an average of $\widehat{\mu_O} = 87\%$ ($\widehat{SE} = 1\%$) of the total integrated mortality was accounted for by the ocean life stage, $\widehat{\mu_J} = 9\%$ ($\widehat{SE} = 1\%$) accounted for by the juvenile inriver migration, and $\widehat{\mu_A} = 4\%$ ($\widehat{SE} = 0.3\%$) accounted for the adult upriver migration. These estimates do not include jacks.

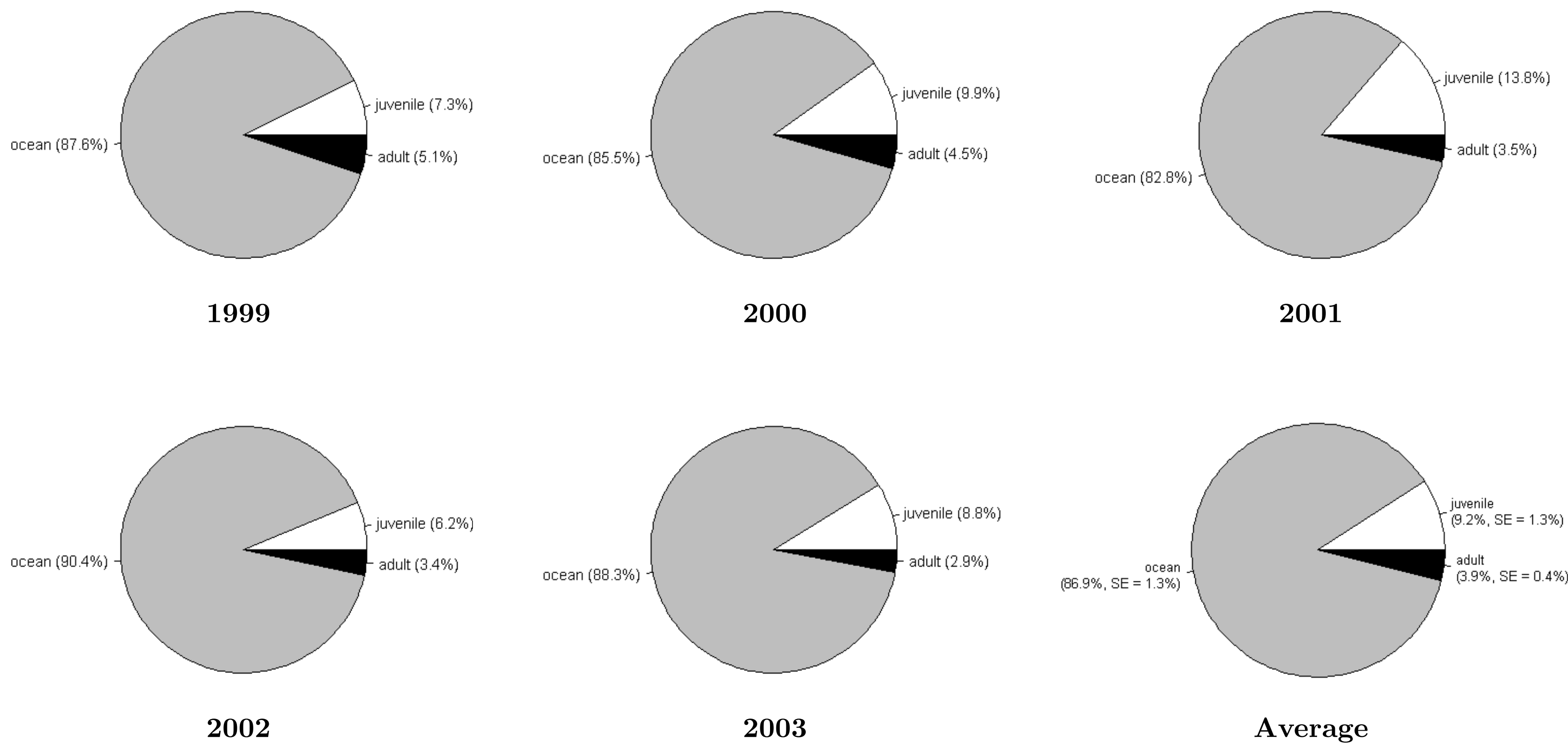


Figure 4.26: The estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for spring Chinook salmon from the Snake River Basin (release area SNB), 1999 to 2003. The last chart shows the average components of total integrated mortality for the 1999 to 2003 release groups, with standard error (SE). The average is the arithmetic average. Estimates do not include jacks.

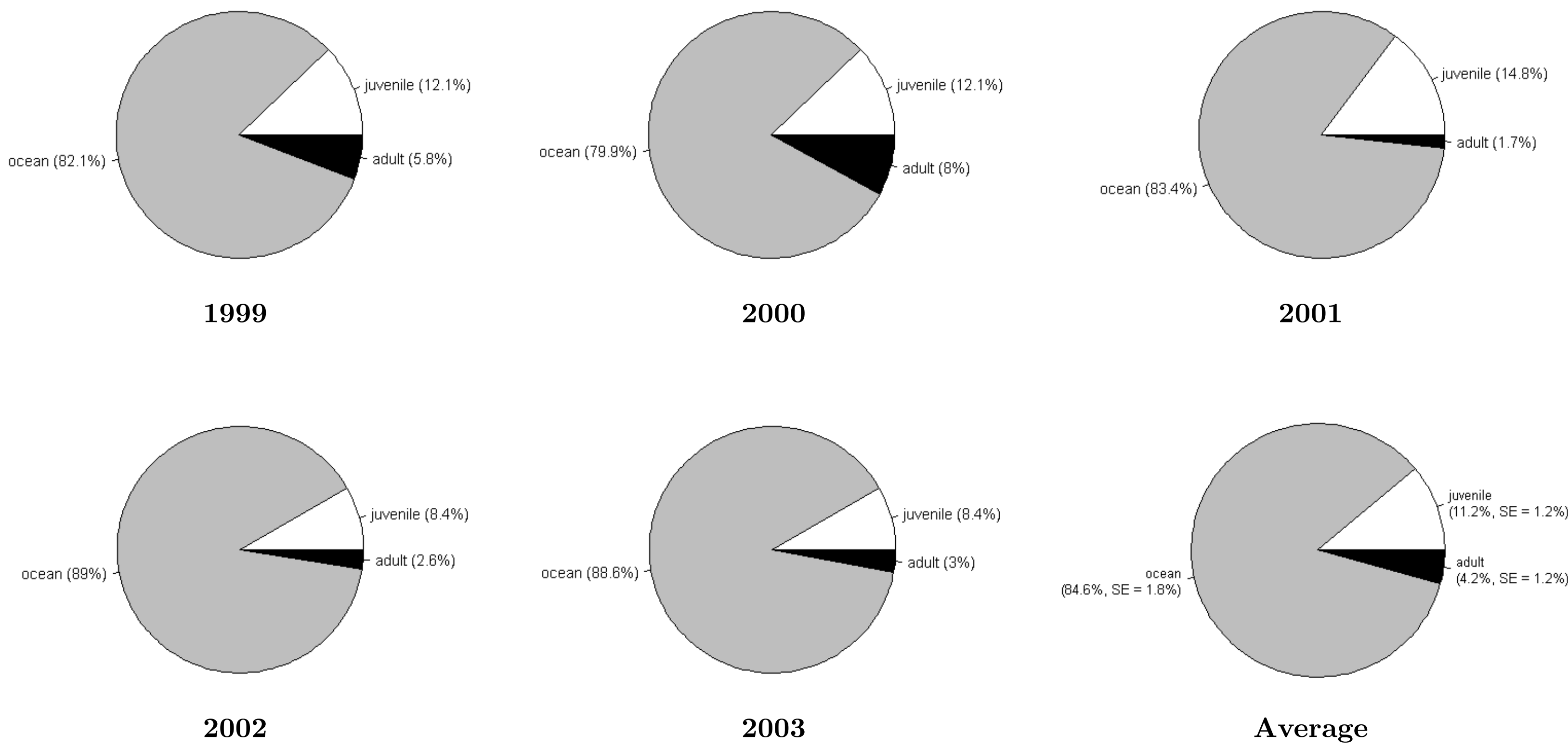


Figure 4.27: The estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for spring Chinook salmon from the Clearwater River (release area CLR), 1999 to 2003. The last chart shows the average components of total integrated mortality for the 1999 to 2003 release groups, with standard error (SE). The average is the arithmetic average. Estimates do not include jacks.

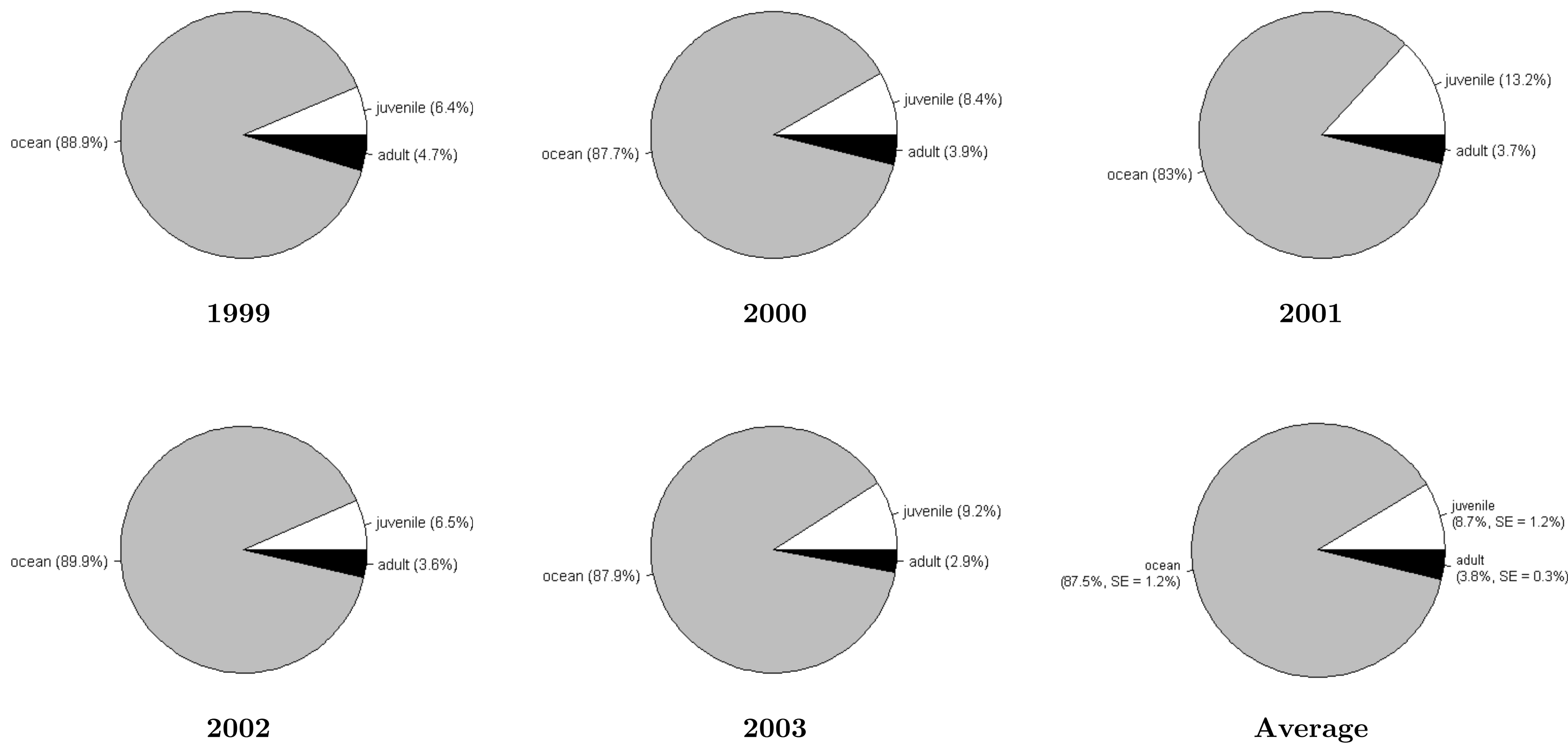


Figure 4.28: The estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for spring Chinook salmon from the Snake River (release area SNK), 1999 to 2003. The last chart shows the average components of total integrated mortality for the 1999 to 2003 release groups, with standard error (SE). The average is the arithmetic average. Estimates do not include jacks.

4.5.2 Hatchery Summer Chinook Salmon

For nontransported summer Chinook salmon, the largest component of the total integrated mortality from 1999 through 2003 (excluding 2001) was ocean mortality (Figure 4.29; Tables G.12-G.14). The ocean life stage contributed an average of $\widehat{\mu_O} = 84\%$ ($\widehat{SE} = 2\%$) of the total integrated mortality between passing LGR as a smolt and returning to LGR as an adult (non-jack) for 1999, 2000, 2002, and 2003. This proportion of total integrated mortality corresponded to an average ocean return probability of 2.77% ($\widehat{SE} = 0.9\%$) for these years. The juvenile migration from LGR to BON accounted for approximately $\widehat{\mu_J} = 12\%$ ($\widehat{SE} = 2\%$) of the total integrated mortality on average, corresponding to an average juvenile inriver survival of 61.3% ($\widehat{SE} = 3.5\%$) for 1999, 2000, 2002, and 2003. On average, the adult migration from BON to LGR accounted for approximately $\widehat{\mu_A} = 4\%$ ($\widehat{SE} = 0.4\%$) of the total integrated mortality for nontransported Snake River summer Chinook, corresponding to an average adult upriver survival of 83.8% ($\widehat{SE} = 1.3\%$) for 1999, 2000, 2002, and 2003. Estimates were unavailable for the 2001 release group because the very few adult detections of nontransported summer Chinook from this release group precluded fitting the ROSTER model for 2001. These estimates do not include jacks.

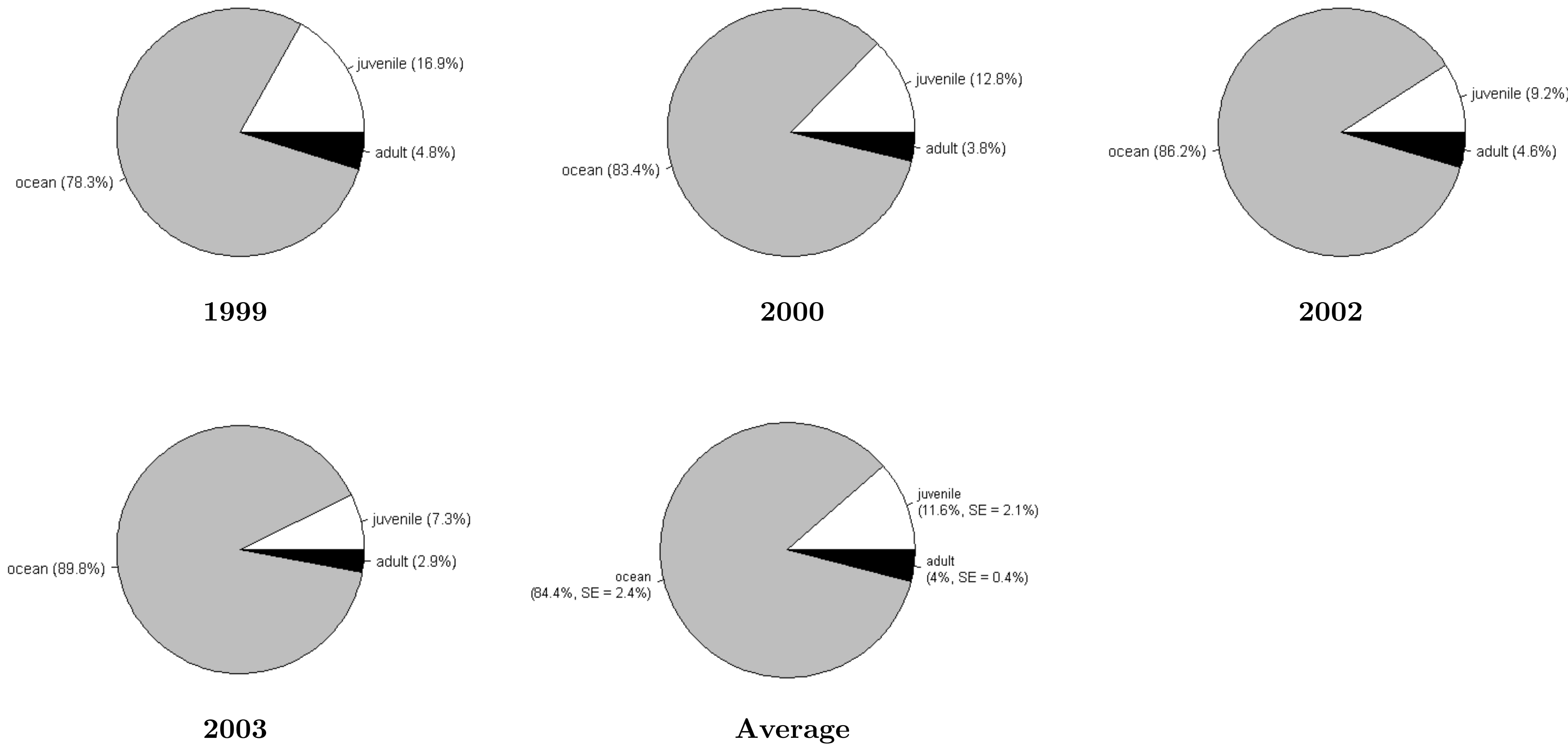


Figure 4.29: The estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for summer Chinook salmon from the Snake River Basin, 1999 to 2003 (excluding 2001). Estimates were unavailable for the 2001 release group because there were too few adult detections of nontransported summer Chinook from that release group. The last chart shows the average components of total integrated mortality for the 1999 to 2003 release groups, with standard error (SE). The average is the arithmetic average. Estimates do not include jacks.

4.5.3 Hatchery Steelhead

For nontransported hatchery steelhead, the largest component of the total integrated mortality between passing LGR as a smolt and returning to LGR as an adult (including age-1-ocean fish) for the years 1999, 2000, 2002, and 2003 came from the ocean life stage (Figure 4.30; Tables G.12-G.14). On average, the ocean life stage accounted for approximately $\widehat{\mu_O} = 74\%$ ($\widehat{SE} = 4\%$) of the total integrated mortality, corresponding to an average ocean return probability of 2.80% ($\widehat{SE} = 0.87\%$) over these years. The juvenile migration from LGR to BON accounted for approximately $\widehat{\mu_J} = 22\%$ ($\widehat{SE} = 4\%$) of the total integrated mortality on average, corresponding to an average juvenile inriver survival of 35.1% ($\widehat{SE} = 5.2\%$) over these years. On average, the adult migration from BON to LGR accounted for approximately 5% ($\widehat{SE} = 0.5\%$) of the total integrated mortality for nontransported steelhead, corresponding to an average adult upriver survival of 79.2% ($\widehat{SE} = 2.0\%$) for the years 1999, 2000, 2002, and 2003. These estimates include the age-1-ocean age class. The very few adult detections of nontransported hatchery steelhead from the 2001 release group made it impossible to compute estimates for that release year.

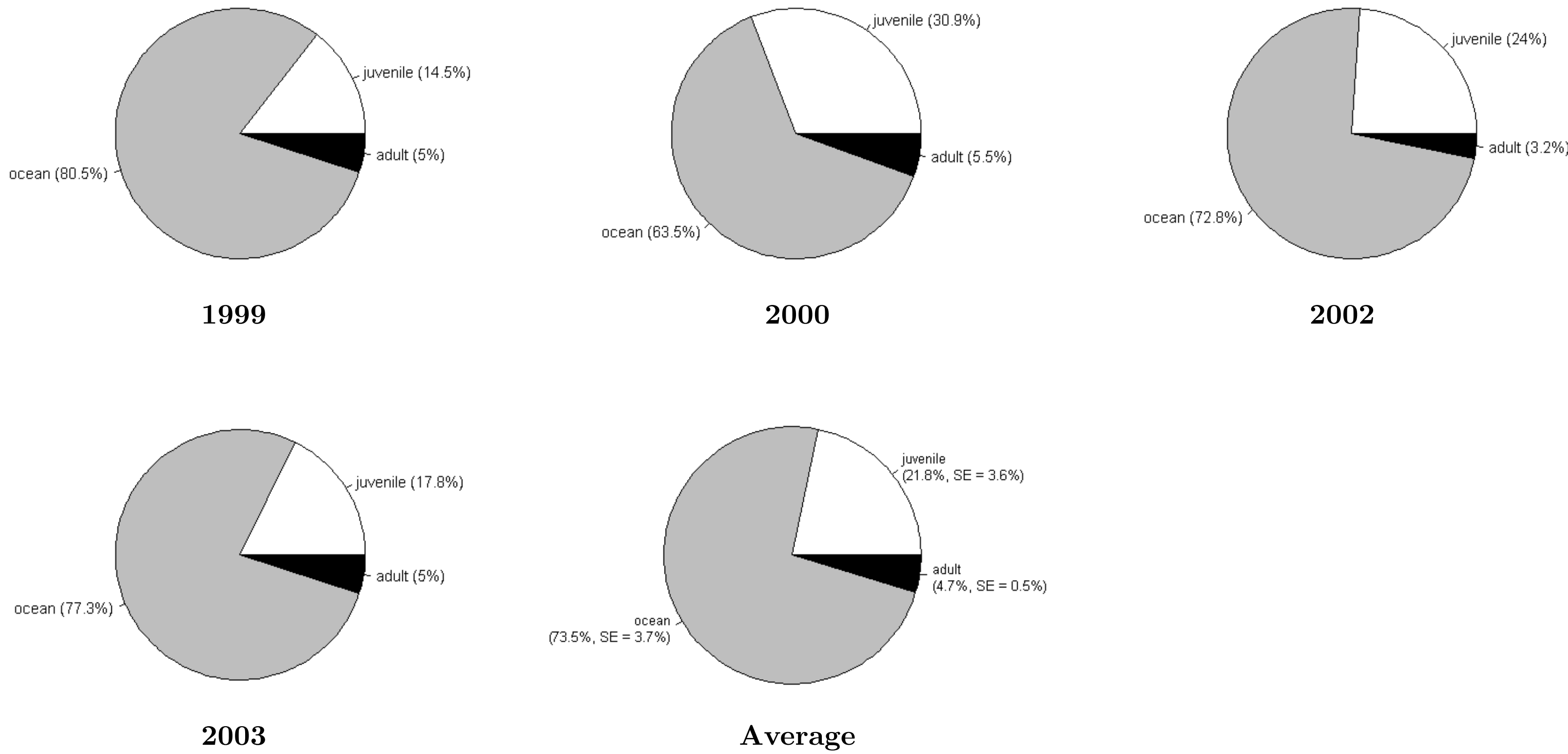


Figure 4.30: The estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for steelhead from the Snake River Basin, 1999 to 2003 (excluding 2001). The last chart shows the average components of total integrated mortality for the 1999 to 2003 release groups, with standard error (SE). Estimates were unavailable for the 2001 release group because there were too few adult detections of nontransported steelhead from that release year. The average is the arithmetic average. Estimates include the age-1-ocean age class.

4.6 Transport-Inriver Ratios

Transport-inriver ratios (T/I) are measured on a systemwide basis (R_{SYS} and R^U_{SYS}), incorporating estimated transportation effects from all transport dams analyzed, and also on a dam-specific basis (R_{LGR}, R_{LGS}). The systemwide T/I measures, R_{SYS} and R^U_{SYS}, incorporate juvenile inriver survival, transportation rates at each transport dam analyzed, ocean return probabilities for both nontransported and transported fish, and adult upriver survival for both nontransported and transported fish. All nontransported fish, including both detected and nondetected fish, are used to estimate survival for nontransported fish and to compare to transported fish. The systemwide T/I measures give the relative return probability to LGR (i.e., the LGR-LGR SAR) of the entire release group under the transportation system as it was operated during the juvenile outmigration, compared to what the expected SAR would have been if the bypass system but not the transportation system had been operated. Values of R_{SYS} or R^U_{SYS} greater than 1.0 indicate that adults returned to Lower Granite at a greater rate with the transportation (as it was operated during the juvenile outmigration) than would have returned in the absence of the transportation system. Only the effects of transportation from the dams with analyzed transport groups (i.e., $\geq 5,000$ tagged fish transported during the release year) are incorporated into these systemwide measures.

Both a tagged (R_{SYS}) and an untagged (R^U_{SYS}) measure of systemwide T/I are estimated. Inference for the untagged systemwide T/I (R^U_{SYS}) is to the tagged release groups, had they been treated as untagged fish at transport dams (i.e., transported at 100% upon detection). The untagged systemwide T/I, R^U_{SYS}, is the systemwide T/I measure under maximal transportation operations.

The dam-specific T/I measures R_{LGR} and R_{LGS} give the relative return probability from the transport dam back to Lower Granite for all fish transported at the transport dam relative to nontransported fish. The reference or control group of nontransported fish for these dam-specific T/I measures includes both detected and nondetected fish, but does not include fish transported from downstream transport dams. Thus, the measures R_{LGR} and R_{LGS} are unconfounded by any transportation from downstream of the transport dam. These measures are analogous to the dam-specific R measures from Sandford and Smith (2002), used by NOAA-Fisheries. Values of R_{LGR} and R_{LGS} greater than 1.0 indicate that fish transported from Lower Granite and Little Goose, respectively, returned to Lower Granite as adults in greater proportions than fish that passed those dams without being transported either there or downriver. Because the measures R_{LGR} and R_{LGS} are each restricted to the transportation effects for a single dam, they have inference to both tagged and untagged fish.

Reported averages are geometric means. The geometric mean is the appropriate measure of the average of a group of ratios, such as T/I values, because it accounts for variation on the multiplicative scale rather than on the additive scale. Averages are reported both with and without the low flow year 2001. No transport groups were analyzed for the 1996 release year because of low numbers of tagged smolts transported in that year. Similarly, because too few ($< 5,000$)

tagged steelhead were transported from transport dams from 1996 to 2003, no results are available for hatchery steelhead. All estimates reported here for Chinook exclude jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

4.6.1 Hatchery Spring Chinook Salmon

The point estimate of the tagged systemwide T/I measure (R_{SYS}) for hatchery spring Chinook from the Snake River Basin (release area SNB; Figure 4.31; Table G.15) was highest for the 2001 release group ($\widehat{R_{SYS}} = 6.15$, $\widehat{SE} = 1.00$), and lowest for the 2002 release group ($\widehat{R_{SYS}} = 1.04$, $\widehat{SE} = 0.01$). The geometric mean of the estimates of the tagged systemwide T/I measure for SNB spring Chinook for release years 1997 to 2003 was 1.47 ($\widehat{SE} = 0.35\%$) if the low flow year 2001 was included, and 1.15 ($\widehat{SE} = 0.03$) if 2001 was excluded (Table 4.1). For SNB spring Chinook, the estimates of R_{SYS} were significantly greater than 1.0 at the 10% significance level for each release year, indicating that the transportation program from 1997 to 2003 resulted in increased returns to Lower Granite, relative to what they would have been if no transportation had occurred. Estimates of the untagged systemwide T/I measure (R^U_{SYS}) for SNB spring Chinook, computed under the assumption of 100% transportation from the JBS at the transport dams analyzed (i.e., Lower Granite for release years 1997 to 2003, and Little Goose for 1998 to 2003), were generally higher and more uncertain than comparable estimates of the tagged systemwide T/I (Figure 4.32; Table G.16). The highest estimate of R^U_{SYS} was 11.44 ($\widehat{SE} = 2.04$) for the 2001 release group, and the lowest estimate was 1.12 ($\widehat{SE} = 0.04$) for the 2002 release group. The geometric average of the $\widehat{R^U_{SYS}}$ values was 1.72 ($\widehat{SE} = 0.55$) if the 2001 estimate is included, and 1.26 ($\widehat{SE} = 0.06$) otherwise. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

Estimates of the systemwide T/I measures for Clearwater spring Chinook are unavailable for the 1996, 1997, 1999, and 2002 release groups because too few ($< 5,000$) tagged Clearwater fish were transported from any dam during those release years. Clearwater estimates of R_{SYS} and R^U_{SYS} are based on transport groups from Lower Granite for release years 1998, 2000, 2001, and 2003, and also on a transport group from Little Goose for the 2000 release year. The highest estimate of the tagged systemwide T/I measure (R_{SYS}) for Clearwater spring Chinook (Figure 4.31; Table G.15) was 3.90 ($\widehat{SE} = 1.28$) for the 2001 release group, and the lowest estimate was 1.02 ($\widehat{SE} = 0.03$) for the 1998 release group. The geometric mean of the point estimates of R_{SYS} over the years 1998, 2000, 2001, and 2003 was 1.49 ($\widehat{SE} = 0.48$) if 2001 is included, and 1.08 ($\widehat{SE} = 0.04$) if 2001 is excluded (Table 4.1). The estimated tagged systemwide T/I measure for Clearwater fish was significantly greater than 1.0 (at the 10% significance level) for the 2000 and 2001 release years, but not for the 1998 or 2003 release years. Estimates of the untagged systemwide T/I measure (R^U_{SYS}) for Clearwater spring Chinook (Figure 4.32; Table G.16) were highest for the 2001 release group ($\widehat{R^U_{SYS}} = 6.49$, $\widehat{SE} = 2.42$) and lowest for the 1998 release group ($\widehat{R^U_{SYS}} = 1.02$, $\widehat{SE} = 0.05$). The geometric mean of R^U_{SYS} estimates over the years 1998, 2000, 2001, and 2003 was 1.74 ($\widehat{SE} = 0.77$) including 2001, and 1.12 ($\widehat{SE} = 0.05$) excluding 2001. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

Estimates of the systemwide T/I measures for Snake River spring Chinook (release area SNK) are based on transport groups from Lower Granite for release years 1997 to 2003, and also on transport groups from Little Goose for release years 1999 to 2003. The highest estimate of the tagged systemwide T/I measure (R_{SYS}) for SNK spring Chinook (Figure 4.31; Table G.15) was for the 2001 release group ($\widehat{S_{SYS}} = 6.58$, $\widehat{SE} = 1.23$), and the lowest estimate was for the 2002 release group ($\widehat{R_{SYS}} = 1.04$, $\widehat{SE} = 0.01$). The geometric mean of the point estimates of R_{SYS} for SNK spring Chinook from 1997 to 2003 is 1.55 ($\widehat{SE} = 0.38$) including 2001, and 1.22 ($\widehat{SE} = 0.07$) excluding 2001 (Table 4.1). The estimated R_{SYS} for SNK spring Chinook was significantly greater than 1.0 (at the 10% significance level) for each release year from 1997 to 2003. Estimates of the untagged systemwide T/I measure (R^U_{SYS}) for SNK spring Chinook ranged from 1.07 ($\widehat{SE} = 0.06$) for the 1997 release group to 12.75 ($\widehat{SE} = 2.59$) for the 2001 release group. The geometric mean of R^U_{SYS} estimates for SNK spring Chinook from 1997 to 2003 was 1.88 ($\widehat{SE} = 0.61$) including the 2001 estimate, and 1.36 ($\widehat{SE} = 0.11$) excluding 2001. These estimates exclude jacks; results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

The dam-specific T/I measure for Lower Granite (R_{LGR}) was estimated for release years 1997 to 2003 for hatchery spring Chinook from the Snake River Basin (release area SNB; Figure 4.33; Table G.17). Estimated R_{LGR} for SNB spring Chinook was highest for the 2001 release group ($\widehat{R_{LGR}} = 13.51$, $\widehat{SE} = 2.43$), and lowest for the 1997 release group ($\widehat{R_{LGR}} = 1.39$, $\widehat{SE} = 0.18$). The geometric mean of the R_{LGR} estimates for SNB spring Chinook from 1997 to 2003 was 2.22 ($\widehat{SE} = 0.67$) including 2001, and 1.64 ($\widehat{SE} = 0.08$) excluding 2001 (Table 4.1). Estimates of R_{LGR} were significantly greater than 1.0 (at the 10% significance level) for SNB spring Chinook for all release years from 1997 to 2003. Estimates of the dam-specific T/I measure for LGR were available for Clearwater hatchery spring Chinook for the 1998, 2000, 2001, and 2003 release years, and ranged from 1.06 ($\widehat{SE} = 0.13$) for the 1998 release group to 8.60 ($\widehat{SE} = 3.34$) for the 2001 release group. The geometric mean of the point estimates for these years was 2.17 ($\widehat{SE} = 1.01$) including 2001, and 1.37 ($\widehat{SE} = 0.17$) excluding 2001 (Table 4.1). The estimate of R_{LGR} was significantly greater than 1.0 (at the 10% significance level) for Clearwater spring Chinook for the 2000, 2001, and 2003 release years, but not for the 1998 release year. Point estimates of the dam-specific T/I measure for LGR for Snake River hatchery spring Chinook (release area SNK) ranged from 1.23 ($\widehat{SE} = 0.18$) for the 1997 release year to 15.40 ($\widehat{SE} = 3.16$) for the 2001 release year. The geometric mean of the R_{LGR} estimates for SNK spring Chinook was 2.45 ($\widehat{SE} = 0.78$) including 2001, and 1.80 ($\widehat{SE} = 0.19$) excluding 2001 (Table 4.1). The estimate of R_{LGR} for SNK hatchery spring Chinook was significantly greater than 1.0 (at the 10% significance level) for each release year from 1997 to 2003. These estimates exclude jacks; results including jacks are available at `http://www.cbr.washington.edu/trends/roster.php`.

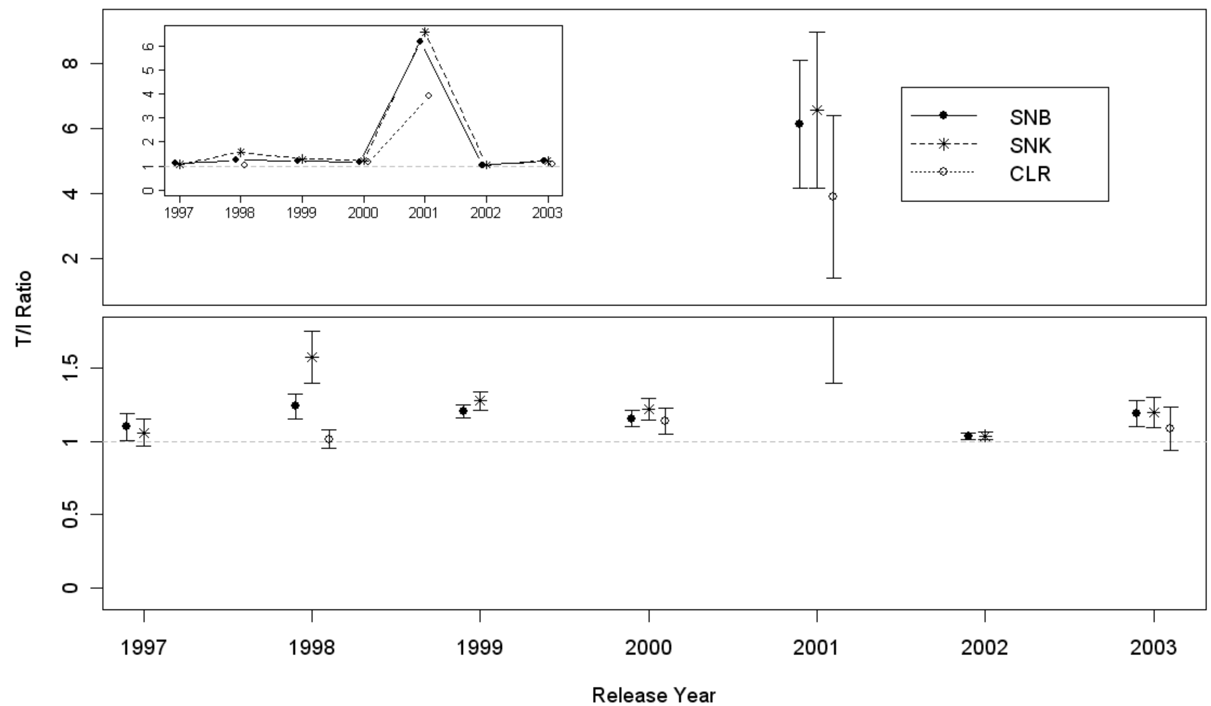


Figure 4.31: Estimated tagged systemwide T/I measure ($\widehat{R_{SYS}}$) for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at T/I = 1. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable for the 1997, 1999, and 2002 release years because too few tagged Clearwater spring Chinook were transported during those years.

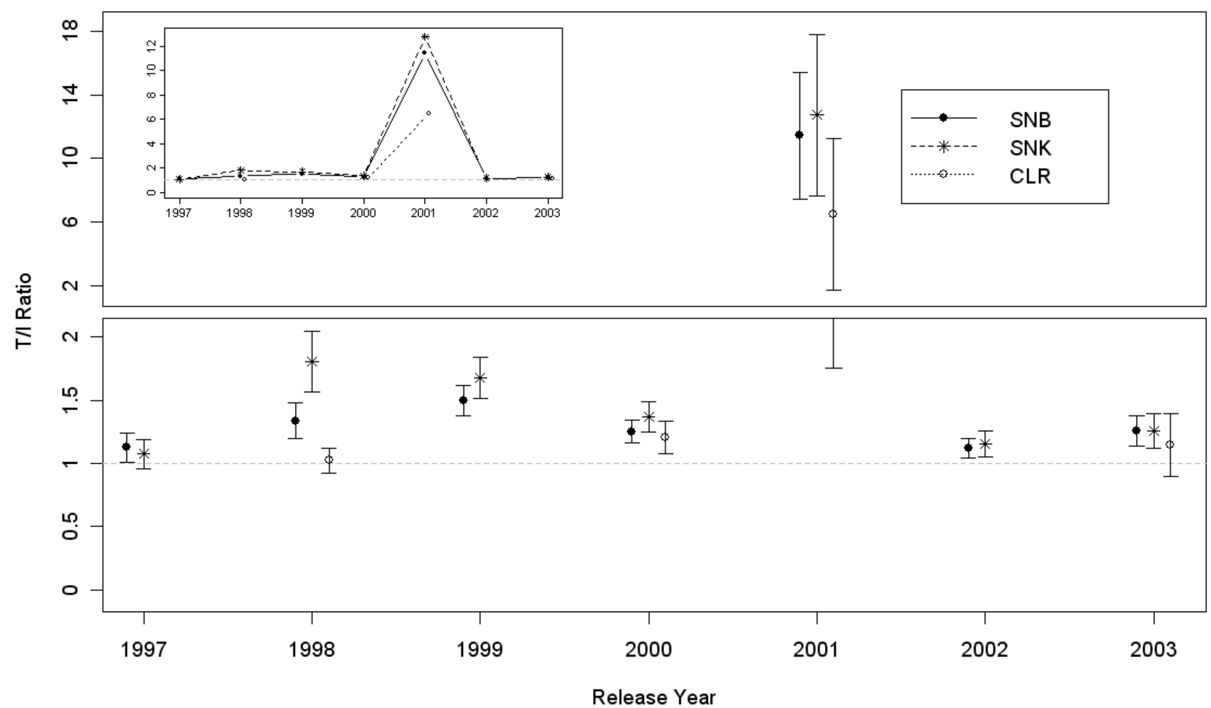


Figure 4.32: Estimated untagged systemwide T/I measure ($\widehat{R^U_{SYS}}$) for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at T/I = 1. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable for the 1997, 1999, and 2002 release years because too few tagged Clearwater spring Chinook were transported during those years.

Fewer tagged hatchery spring Chinook were transported from Little Goose than from Lower Granite from 1996 to 2003, resulting in fewer LGS-transport groups analyzed. Transport groups from Little Goose were analyzed in release years from 1998 to 2003 for SNB spring Chinook, from 1999 to 2003 for SNK spring Chinook, and only for the 2003 release year for Clearwater spring Chinook (Figure 4.34; Table G.18). Estimates of the dam-specific T/I measure for Little Goose (R_{LGS}) for SNB spring Chinook ranged from 0.93 ($\widehat{SE} = 0.14$) for the 1998 release group to 7.13 ($\widehat{SE} = 1.60$) for the 2001 release group. The geometric mean of R_{LGS} estimates for SNB spring Chinook was 1.57 ($\widehat{SE} = 0.49$) including 2001, and 1.16 ($\widehat{SE} = 0.12$) excluding 2001 (Table 4.1). The estimate of R_{LGS} for SNB spring Chinook was significantly greater than 1.0 (at the 10% significance level) for release years 1999 and 2001, but not for release years 1998, 2000, 2002, or 2003. The single estimate of the dam-specific T/I measure for Little Goose (R_{LGS}) for Clearwater hatchery spring Chinook was 1.01 ($\widehat{SE} = 0.12$) for the 2000 release group; this estimate is not significantly greater than 1.0. The highest estimate of R_{LGS} for SNK hatchery spring Chinook was 6.29 ($\widehat{SE} = 1.71$) for the 2001 release group, and the lowest was 1.11 ($\widehat{SE} = 0.15$) for the 2003 release group. The geometric mean of the R_{LGS} estimates for SNK spring Chinook was 1.78 ($\widehat{SE} = 0.60$) including 2001, and 1.30 ($\widehat{SE} = 0.19$) excluding 2001. The estimate of R_{LGS} for SNK spring Chinook was significantly greater than 1.0 (at the 10% significance level) for the 1999, 2000, and 2001 release groups, but not for the 2002 or 2003 release groups. Estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

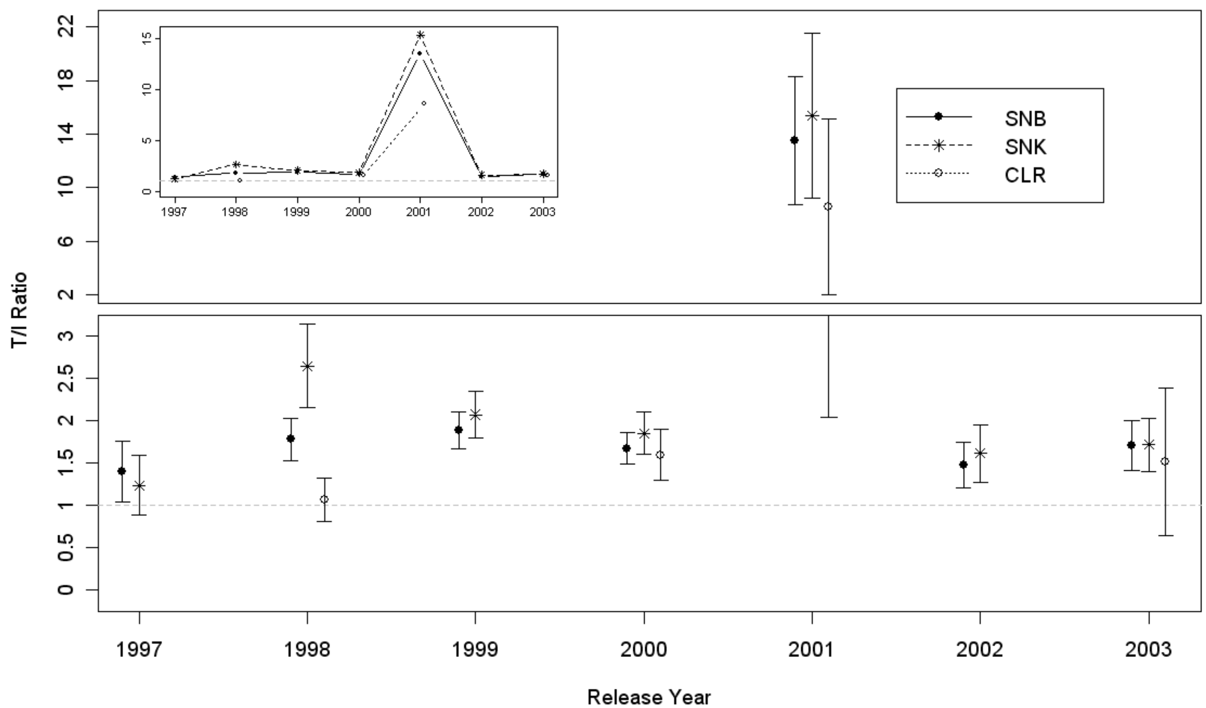


Figure 4.33: Estimated T/I measure for Lower Granite ($\widehat{R_{LGR}}$) for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at T/I = 1. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable for the 1997, 1999, and 2002 release years because too few tagged Clearwater spring Chinook were transported from Lower Granite in those years to analyze LGR-transport groups.

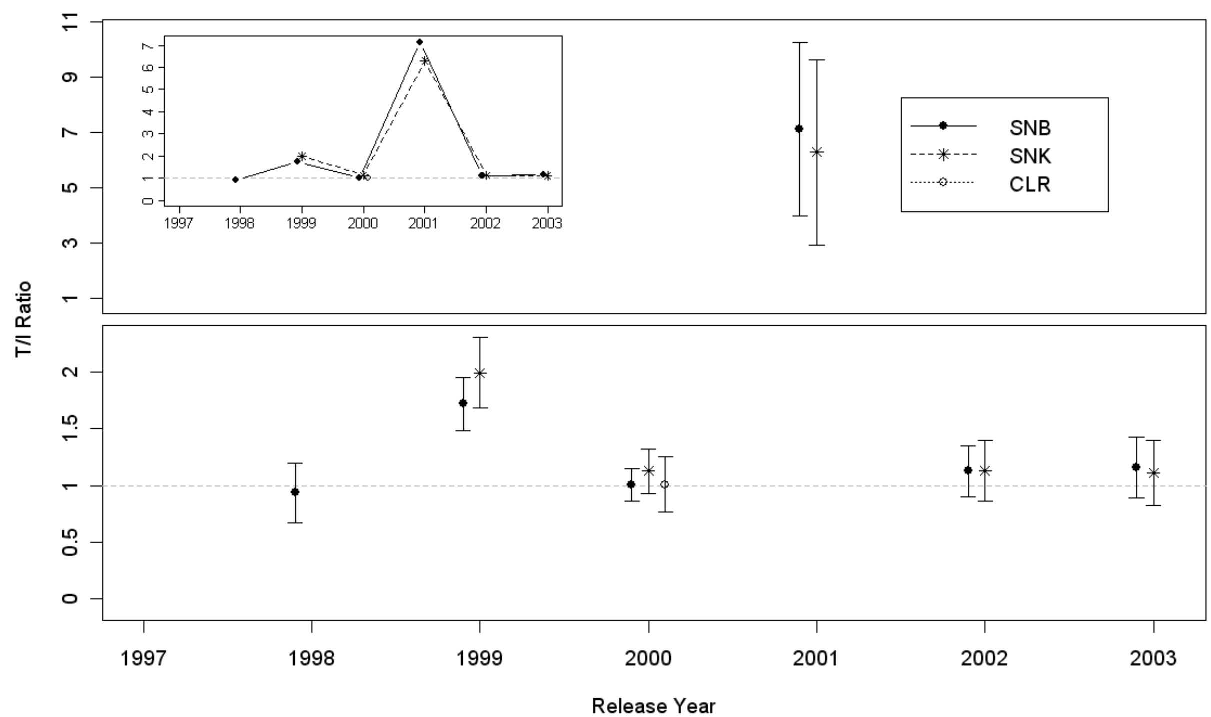


Figure 4.34: Estimated T/I measure for Little Goose ($\widehat{R_{LGS}}$) for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at T/I = 1. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable for all release years except 2000 because too few tagged Clearwater spring Chinook were transported from Little Goose in other years to analyze LGS-transport groups for those years.

4.6.2 Hatchery Summer Chinook Salmon

Transportation effects on adult returns of hatchery summer Chinook salmon were analyzed for Lower Granite transportation for release years 1997, 1998, 2000, 2001, and 2003, and for Little Goose transportation for the 1999 release year. Too few ($< 5,000$) tagged hatchery summer Chinook were transported from Lower Granite in 1999 and 2002 to analyze LGR-transport groups for those release years, and likewise for Little Goose in all release years except 1999. No summer Chinook transportation effects were estimated for the 2002 release group. Thus, systemwide T/I measures (R_{SYS} and R_{SYS}^{U}) reflect effects of transportation only from Lower Granite for all release years except for 1999, when effects of transportation only from Little Goose are included. Very low numbers of adult detections of nontransported smolts from the 2001 release group made it impossible to use the full ROSTER model to analyze the 2001 summer Chinook release group. Instead, heuristic (i.e., non-ROSTER) estimates of both dam-specific and systemwide T/I measures were computed for the 2001 release group. These measures are equivalent (in expectation) to the estimates produced by the ROSTER model (see Appendix E.5 for more details). The estimates presented here do not include jacks. Additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

The estimated tagged systemwide T/I measure ($\widehat{R_{SYS}}$) for hatchery summer Chinook (Figure 4.35; Table G.15) was highest for the 2001 release group ($\widehat{R_{SYS}} = 13.51$, $\widehat{SE} = 4.38$), and lowest for the 1999 release group ($\widehat{R_{SYS}} = 1.08$, $\widehat{SE} = 0.02$). The geometric mean of the estimates of R_{SYS} from 1997 to 2003 (excluding 2002) was 1.89 ($\widehat{SE} = 0.76$) if the 2001 estimate is included, and 1.28 ($\widehat{SE} = 0.13$) otherwise (Table 4.1). Estimates of R_{SYS} were significantly greater than 1.0 (at the 10% significance level) for hatchery summer Chinook for all release years from 1997 through 2003, except for 2002 when no summer Chinook transport group was analyzed. Estimates of the untagged systemwide T/I measure ($\widehat{R_{SYS}^{U}}$) for hatchery summer Chinook (Figure 4.36; Table G.16) ranged from 1.13 ($\widehat{SE} = 0.06$) for the 1999 release group to 29.78 ($\widehat{SE} = 10.08$) for the 2001 release. The geometric mean of the R_{SYS}^{U} estimates for hatchery summer Chinook for release years 1997 to 2003 (excluding 2002) was 2.34 ($\widehat{SE} = 1.21$) if the 2001 estimate was included, and 1.41 ($\widehat{SE} = 0.17$) if the 2001 estimate was excluded. As described above, both the tagged and untagged estimate for the 2001 release year was produced outside the full ROSTER model.

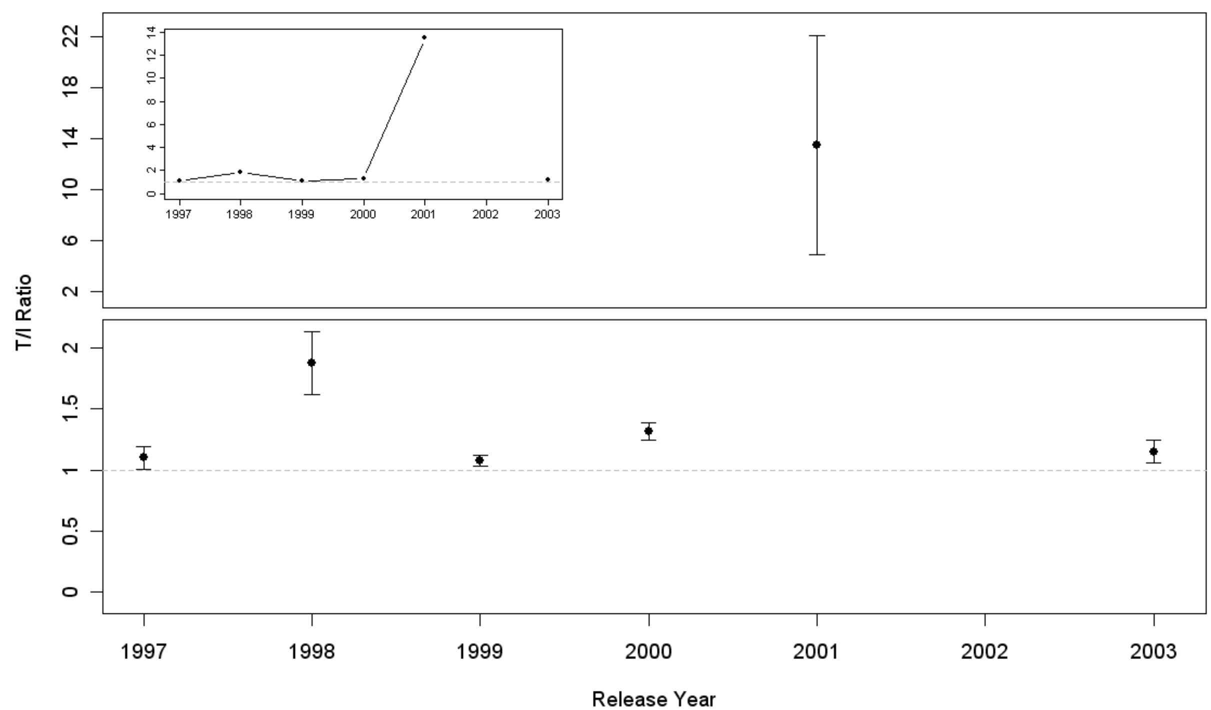


Figure 4.35: Estimated tagged systemwide T/I measure $(\widehat{R_{SYS}})$ for summer Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at T/I = 1. Estimates do not include jacks. The 2001 estimate is heuristic, produced outside the full ROSTER model. No estimate is available for the 2002 release year because too few tagged summer Chinook were transported from any dam during that year to analyze a transport group.

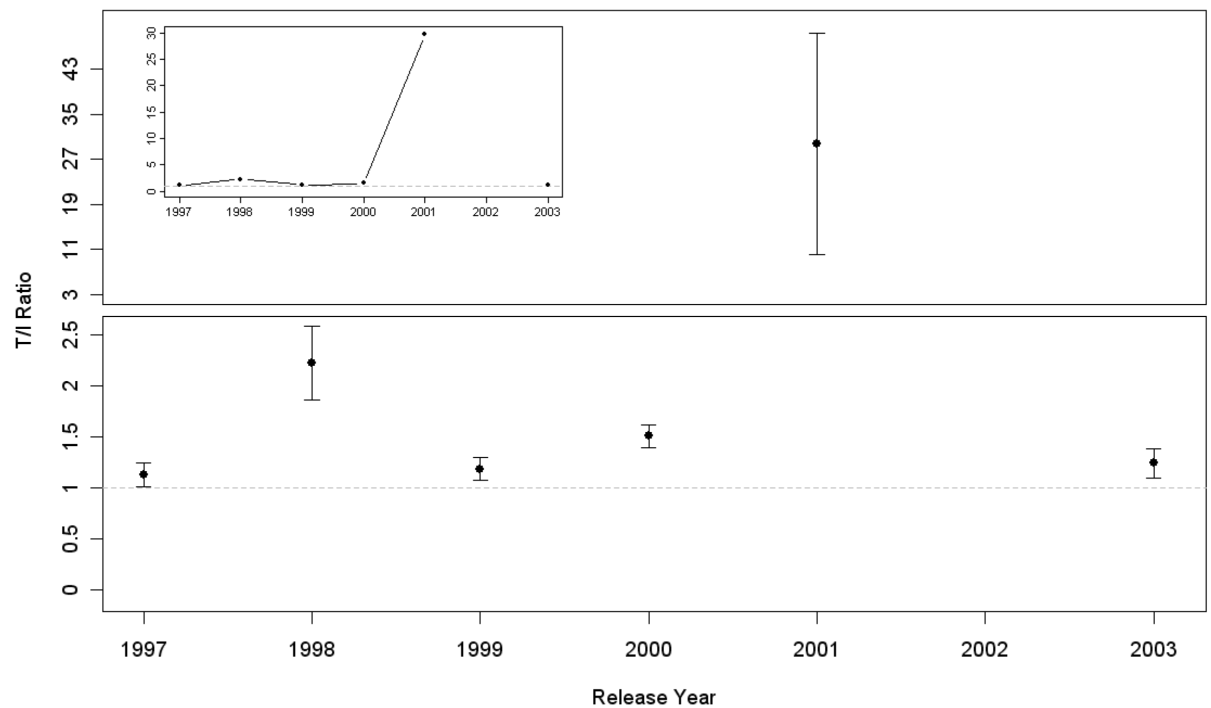


Figure 4.36: Estimated untagged systemwide T/I measure ($\widehat{R^U_{SYS}}$) for summer Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at T/I = 1. Estimates do not include jacks. The 2001 estimate is heuristic, produced outside the full ROSTER model. No estimate is available for the 2002 release year because too few tagged summer Chinook were transported from any dam during that year to analyze a transport group.

Dam-specific T/I measures specific to Lower Granite transportation (R_{LGR}) were estimable for summer Chinook for the 1997, 1998, 2000, 2001, and 2003 release years (Figure 4.37; Table G.17). Over these five release years, the highest estimate of R_{LGR} was for 2001 ($\widehat{R_{LGR}} = 37.70$, $\widehat{SE} = 12.86$), and the lowest estimate was for 1997 ($\widehat{R_{LGR}} = 1.36$, $\widehat{SE} = 0.17$). The geometric mean of the R_{LGR} estimates for summer Chinook over these years was 3.77 ($\widehat{SE} = 2.26$) including 2001, and 2.12 ($\widehat{SE} = 0.45$) excluding 2001 (Table 4.1). For all five of these release years, the estimate of R_{LGR} was significantly greater than 1.0 (at the 10% significance level) for hatchery summer Chinook salmon. The estimate of R_{LGR} for 2001 was a heuristic estimate, produced outside the full ROSTER model. The single estimate of the dam-specific T/I measure specific to Little Goose (R_{LGS}) for summer Chinook was for the 1999 release year (Table G.18), when R_{LGS} was estimated at 1.38 ($\widehat{SE} = 0.12$). This estimate of R_{LGS} was significantly greater than 1.0, at the 10% significance level. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

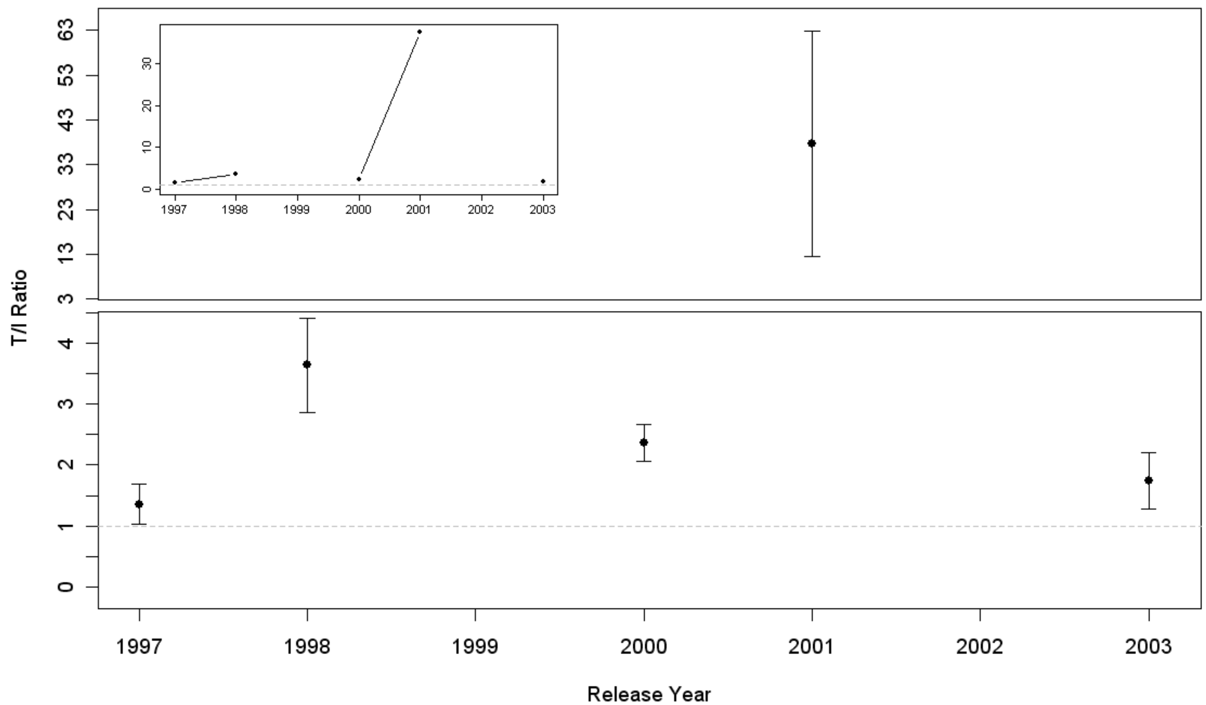


Figure 4.37: Estimated T/I measure for Lower Granite ($\widehat{R_{LGR}}$) for summer Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at T/I = 1. Estimates do not include jacks. The 2001 estimate is heuristic, produced outside the full ROSTER model. No estimate is available for the 2002 release year because too few tagged summer Chinook were transported from any dam during that year to analyze a transport group.

4.6.3 Transport-Inriver Ratio Summary

Table 4.1 summarizes the T/I results for spring and summer Chinook salmon. Results are classified by project, where "System" represents the tagged systemwide T/I (R_{SYS}). For each project, run (spring or summer), and release area, the average observed measure is presented with and without 2001 data, and the measure for 2001 is shown separately. The average is the geometric mean. Also, the one-tailed P-value from the meta analysis testing whether the T/I measure is greater than 1.0 is shown. Only results for the tagged release groups are shown; the untagged T/I measure (R^U_{SYS}) is omitted. Except for Clearwater spring Chinook transported from Little Goose Dam, the estimated T/I ratio is significantly greater than 1.0 in all cases.

Table 4.1: Summary table of T/I results for tagged spring and summer Chinook. Project = "System" represents R_{SYS}. Average is geometric mean. Values in parentheses are the standard errors of the point estimates to the left. The one-tailed P-value is from meta analysis testing if the T/I measure is greater than 1.0.

			Average T/I			
Project	**Run**	**Release Area**	**Including** 2001	**Excluding** 2001	**Only** 2001	**1-Tailed** ***P*-value**
System	Spring	CLR	1.4884 (0.4789)	1.0798 (0.0363)	3.8977 (1.2759)	< 0.0001
LGR	Spring	CLR	2.1660 (1.0143)	1.3680 (0.1749)	8.5965 (3.3444)	< 0.0001
LGS	Spring	CLR	1.0070 (-)	1.0070 (-)	NA (-)	0.4773
System	Spring	SNK	1.5501 (0.3821)	1.2182 (0.0750)	6.5795 (1.2303)	< 0.0001
LGR	Spring	SNK	2.4477 (0.7807)	1.8015 (0.1881)	15.3965 (3.1551)	< 0.0001
LGS	Spring	SNK	1.7773 (0.5952)	1.2960 (0.1866)	6.2857 (1.7051)	< 0.0001
System	Spring	SNB	1.4654 (0.3518)	1.1539 (0.0312)	6.1471 (1.0043)	< 0.0001
LGR	Spring	SNB	2.2174 (0.6736)	1.6407 (0.0769)	13.5109 (2.4332)	< 0.0001
LGS	Spring	SNB	1.5695 (0.4942)	1.1595 (0.1228)	7.1320 (1.5984)	< 0.0001
System	Summer	SNB	1.8897 (0.7601)	1.2751 (0.1311)	13.5077 (4.3831)	< 0.0001
LGR	Summer	SNB	3.7747 (2.2588)	2.1232 (0.4507)	37.7047 (12.8628)	< 0.0001
LGS	Summer	SNB	1.3806 (-)	1.3806 (-)	NA (-)	0.0001

4.7 Differential Post-Bonneville Mortality (D)

Differential post-Bonneville mortality, D, is the ratio of survival from passing Bonneville as a juvenile to returning to Lower Granite as an adult for transport fish relative to that of nontransported fish. Differential post-Bonneville mortality is measured both on a systemwide basis (D_{SYS} and D^U_{SYS}), incorporating estimated transportation effects from all transport dams analyzed, and also on a dam-specific basis (D_{LGR}, D_{LGS}). Both the systemwide measures and the dam-specific measures incorporate juvenile survival of nontransported fish, survival of transport fish during transportation (assumed to be 98%), transportation probabilities at each transport dam analyzed, ocean return probabilities for both transported and nontransported fish, and adult upriver survival for both transported and nontransported fish. All nontransported fish, including both detected and nondetected fish, are used to estimate survival for nontransported fish and to compare to transported fish. All transport fish from analyzed transport groups (i.e., from dams with at least 5,000 tagged smolts transported during the release year) are used to estimate the ocean return probability and adult upriver survival of transport fish, including fish that were detected at dams upstream of their transport dam. The systemwide D measures give the ratio of post-Bonneville survival for two groups of fish: fish that were transported and survived to Bonneville as smolts, and fish that survived to Bonneville as smolts without being transported. Values of D_{SYS} or D^U_{SYS} greater than 1.0 indicate that relatively more transported fish returned from Bonneville to Lower Granite from the release group than fish that reached Bonneville inriver (i.e., nontransported). Values of D_{SYS} or D^U_{SYS} greater than juvenile inriver survival (S_J) indicate that transported fish returned from Lower Granite back to Lower Granite in higher proportions than nontransported fish.

Both a tagged (D_{SYS}) and an untagged (D^U_{SYS}) measure of systemwide D are estimated. Inference for the untagged systemwide D (D^U_{SYS}) is to the tagged release groups, had they been treated as untagged fish at transport dams (i.e., transported at 100% upon detection). The untagged systemwide D, D^U_{SYS}, is the systemwide D measure under maximal transportation operations. If there is only a single transport dam for a given release group, then the tagged and untagged measures of post-Bonneville mortality will be equal for that release group (i.e., $D_{SYS} = D^U_{SYS}$).

The dam-specific D measures (D_{LGR} and D_{LGS}) give the relative return probability from Bonneville (as a smolt) back to Lower Granite for Lower Granite and Little Goose transport fish, respectively, compared to the return probability for nontransported fish. The reference group of nontransported fish for these dam-specific D measures includes both detected and nondetected smolts, but does not include fish transported from downstream dams. The measures D_{LGR} and D_{LGS} are analogous to the dam-specific D measures estimated by NOAA-Fisheries (Williams et al. 2005). Because the measures D_{LGR} and D_{LGS} are each restricted to the transportation effects for a single dam, they have inference to both tagged and untagged fish.

Averages reported are geometric means. Averages are reported both with and without data from the low flow year 2001. No transport groups were analyzed for the 1996 release year because fewer than 5,000 tagged smolts were transported from any transport dam in any release group for that year. Similarly, because fewer than 5,000 tagged steelhead were transported from transport dams from 1996 to 2003, no results are available for hatchery steelhead. Additionally, because estimating D depends on inriver survival of nontransported fish, no estimate of D is available for release groups that could not be estimated using the full ROSTER model (i.e., 2001 summer Chinook). All estimates reported here exclude jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

4.7.1 Hatchery Spring Chinook Salmon

Estimates of the systemwide D measures D_{SYS} and D^U_{SYS} for hatchery spring Chinook from the Snake River Basin (release area SNB; Figure 4.38; Table G.19) were based on transportation at Lower Granite for release years 1997 to 2003, and also on transportation at Little Goose for release years 1998 to 2003. The untagged measure D^U_{SYS} was estimated under the assumption of 100% transportation from the JBS at the transport dams. The point estimate of the tagged systemwide D measure (D_{SYS}) for SNB spring Chinook was highest for the 2001 release group ($\widehat{D_{SYS}} = 4.48$, $\widehat{SE} = 1.52$), and lowest for the 1997 release group ($\widehat{D_{SYS}} = 0.72$, $\widehat{SE} = 0.24$). The geometric average of the D_{SYS} estimates for SNB spring Chinook for release years 1997 to 2003 was 1.24 ($\widehat{SE} = 0.28$) if the 2001 estimate is included, and 1.00 ($\widehat{SE} = 0.09$) if the 2002 estimate is excluded (Table 4.2). For SNB spring Chinook, the estimate of D_{SYS} was significantly greater than 1.0 at the 10% significance level for the 1999 and 2001 release years, but not for the other release years. Estimates of the untagged systemwide D measure ($\widehat{D^U_{SYS}}$) for hatchery SNB spring Chinook ranged from 0.72 ($\widehat{SE} = 0.24$) for the 1997 release group to 4.46 ($\widehat{SE} = 1.51$) for the 2001 release group (Figure 4.39; Table G.20). The average estimate of D^U_{SYS} for SNB spring Chinook over the 1997 to 2003 release years was 1.22 ($\widehat{SE} = 0.28$) if the 2001 estimate is included, and 0.99 ($\widehat{SE} = 0.08$) otherwise. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

The systemwide D measures D_{SYS} and D^U_{SYS} were estimated for the 1998, 2000, 2001, and 2003 release years for spring Chinook from the Clearwater River (release area CLR; Figure 4.38; Table G.19). Low numbers of tagged Clearwater spring Chinook transported in 1997, 1999, and 2002 resulted in no Clearwater transport groups being analyzed for those release years. The systemwide D measures represent transportation at Lower Granite for the release years 1998, 2000, 2001, and 2003, and also Little Goose for the 2000 release year. The highest estimate of the tagged systemwide D for Clearwater spring Chinook was for the 2001 release group ($\widehat{D_{SYS}} = 2.75$, $\widehat{SE} = 1.68$), and the lowest estimate was for the 1998 release group ($\widehat{D_{SYS}} = 0.62$, $\widehat{SE} = 0.08$). The geometric average of the tagged systemwide D values for Clearwater fish over the years with estimates was 1.07 ($\widehat{SE} = 0.35$) if the 2001 estimate is included, and 0.79 ($\widehat{SE} = 0.09$) otherwise (Table 4.2). Only for the 2001 release year was $\widehat{D_{SYS}}$ significantly greater than 1.0 at the 10% level for Clearwater fish. Because only the 2000 release group had transportation at both Lower Granite and Little

Goose, only the 2000 estimate of the untagged systemwide D measure differs from the tagged estimate. For 2000, the untagged D measure for Clearwater fish was $\widehat{D^U_{SYS}} = 0.86$ ($\widehat{SE} = 0.13$; Figure 4.39; Table G.20). The tagged and untagged measures of D have the same average estimates for Clearwater spring Chinook. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

Transport groups of Snake River spring Chinook (release area SNK) were analyzed for Lower Granite for release years 1997 to 2003, and for Little Goose for release years 1999 to 2003. Thus, the systemwide D measures D_{SYS} and D^U_{SYS} were based on transportation from Lower Granite from 1997 to 2003, and also on transportation from Little Goose from 1999 onward. The highest estimate of the tagged systemwide D measure for SNK spring Chinook (Figure 4.38; Table G.19) was for the 2001 release group ($\widehat{D_{SYS}} = 5.32$, $\widehat{SE} = 2.00$), and the lowest was for the 1997 release group ($\widehat{D_{SYS}} = 0.77$, $\widehat{SE} = 0.29$). The average D_{SYS} estimate for SNK spring Chinook from 1997 to 2003 was 1.44 ($\widehat{SE} = 0.35$) if the 2001 estimate is included, and 1.16 ($\widehat{SE} = 0.14$) otherwise (Table 4.2). The untagged systemwide D measure, D^U_{SYS}, was identical to the tagged measure for the 1997 and 1998 release groups because only Lower Granite transportation was analyzed for SNK spring Chinook for those release years. Estimates of the untagged measure ($\widehat{D^U_{SYS}}$) ranged from 0.77 ($\widehat{SE} = 0.29$) for the 1998 release group to 5.31 ($\widehat{SE} = 2.00$) for the 2001 release group, with identical average estimates as the tagged measure (Figure 4.39; Table G.20). The estimate of D_{SYS} for SNK fish was significantly greater than 1.0 from 1998 to 2001 at the 10% level, but not in 1997, 2002, or 2003. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

The dam-specific D measure for Lower Granite (D_{LGR}) was estimated for release years 1997 through 2003 for hatchery spring Chinook from the Snake River Basin (release area SNB; Figure 4.40; Table G.21). Estimates of D_{LGR} range from 0.72 ($\widehat{SE} = 0.24$) for the 1997 release group to 4.90 ($\widehat{SE} = 1.67$) for the 2001 release group for SNB spring Chinook. The geometric mean of the D_{LGR} estimates for SNB spring Chinook was 1.32 ($\widehat{SE} = 0.30$) if 2001 is included, and 1.06 ($\widehat{SE} = 0.09$) otherwise (Table 4.2). The estimate of D_{LGR} for SNB spring Chinook was significantly greater than 1.0 at the 10% significance level for 1999 and 2001 release years, but not for the other release years. Estimates of D_{LGR} are available for Clearwater spring Chinook for the 1998, 2000, 2001, and 2003 release years; other release years had too few tagged Clearwater spring Chinook transported from Lower Granite to analyze LGR-transport effects. For the four years with estimates, $\widehat{D_{LGR}}$ was highest for the 2001 release group ($\widehat{D_{LGR}} = 2.74$, $\widehat{SE} = 1.68$) and lowest for the 1998 release group ($\widehat{D_{LGR}} = 0.62$, $\widehat{SE} = 0.08$) for Clearwater spring Chinook. The average estimate of D_{LGR} for Clearwater spring Chinook was 1.09 ($\widehat{SE} = 0.35$) if the 2001 release group is included, and 0.80 ($\widehat{SE} = 0.10$) otherwise (Table 4.2). Only for the 2001 release year was the estimate of D_{LGR} significantly greater than 1.0 (at the 10% significance level) for Clearwater spring Chinook. Estimates of D_{LGR} for Snake River spring Chinook (release area SNK; Figure 4.40; Table G.21) were available for all release years from 1997 to 2003, ranging from 0.77 ($\widehat{SE} = 0.29$) for the 1997 release to 5.96 ($\widehat{SE} = 2.24$) for the 2001 release. The average dam-specific D measure for Lower Granite for SNK spring Chinook over these years was 1.52 ($\widehat{SE} = 0.38$) if the 2001 estimate is included, and 1.21 ($\widehat{SE} = 0.14$) otherwise (Table 4.2). The estimate of D_{LGR} for SNK spring Chinook was significantly greater than 1.0 (at the 10% significance level) for the 1998, 1999, 2000, and 2001 release groups. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

The dam-specific D measure for Little Goose (D_{LGS}) was estimated for the SNB spring Chinook for release years 1998 through 2003 (Figure 4.41; Table G.22), ranging from 0.61 ($\widehat{SE} = 0.12$) for the 1998 release group to 2.72 ($\widehat{SE} = 0.99$) for the 2001 release group. The geometric mean of the D_{LGS} estimates for SNB spring Chinook from 1998 to 2003 was 1.04 ($\widehat{SE} = 0.23$) if 2001 is included, and 0.86 ($\widehat{SE} = 0.12$) otherwise (Table 4.2). The estimate of D_{LGS} for SNB spring Chinook was significantly greater than 1.0 at the 10% significance level for 1999 and 2001 release years, but not for the other release years. The single estimate of the dam-specific D measure for Little Goose for Clearwater spring Chinook (release area CLR) was for the 2000 release group, when D_{LGS} was estimated at 0.74 ($\widehat{SE} = 0.13$); this estimate was not significantly greater than 1.0 at the 10% level of significance. Estimates of D_{LGS} are available for Snake River spring Chinook (release area SNK) for the 1999 through 2003 release years. The highest estimate of D_{LGS} for SNK spring Chinook was for the 2001 release year ($\widehat{D_{LGS}} = 2.54$, $\widehat{SE} = 1.06$), and the lowest estimate was for the 2003 release year ($\widehat{D_{LGS}} = 0.72$, $\widehat{SE} = 0.12$). The average estimate of D_{LGS} for SNK spring Chinook from 1999 to 2003 was 1.22 ($\widehat{SE} = 0.28$) if 2001 is included, and 1.01 ($\widehat{SE} = 0.18$) if 2001 is excluded (Table 4.2). The estimate of D_{LGS} for SNK spring Chinook was significantly greater than 1.0 (at the 10% significance level) for the 1999 and 2001 release groups, but not for the 2000, 2002, or 2003 release groups. These estimates do not include jacks; additional results including jacks are available online at `http://www.cbr.washington.edu/trends/roster.php`.

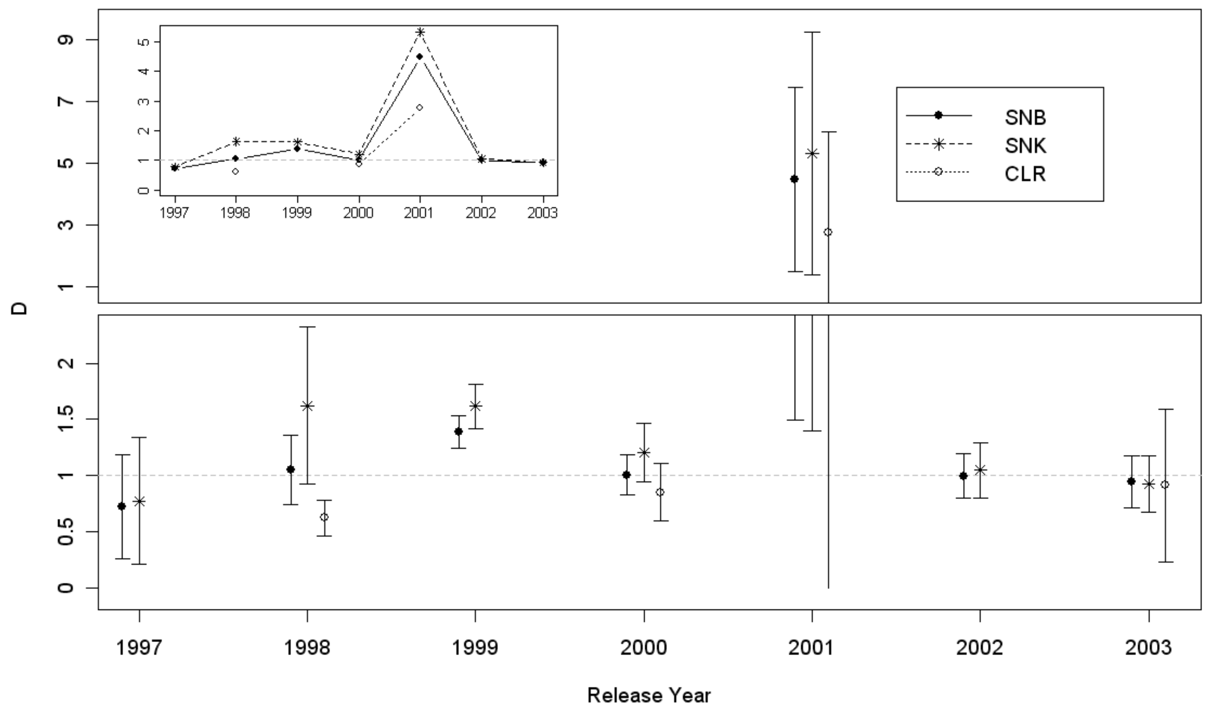


Figure 4.38: Estimated tagged systemwide D measure ($\widehat{D_{SYS}}$) for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at $D = 1$. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable for the 1997, 1999, and 2002 release groups because too few tagged Clearwater spring Chinook were transported in those release years.

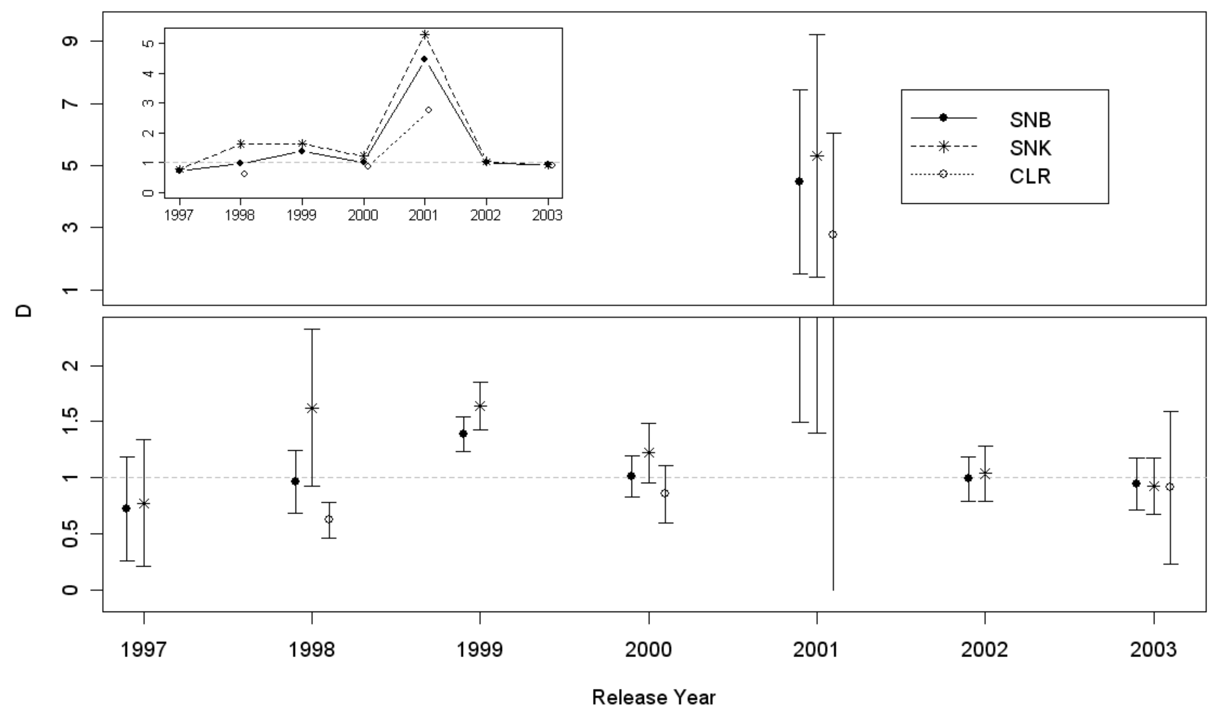


Figure 4.39: Estimated untagged systemwide D measure $(\widehat{D^{U}_{SYS}})$ for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at $D = 1$. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were unavailable for the 1997, 1999, and 2002 release groups because too few tagged Clearwater spring Chinook were transported in those release years

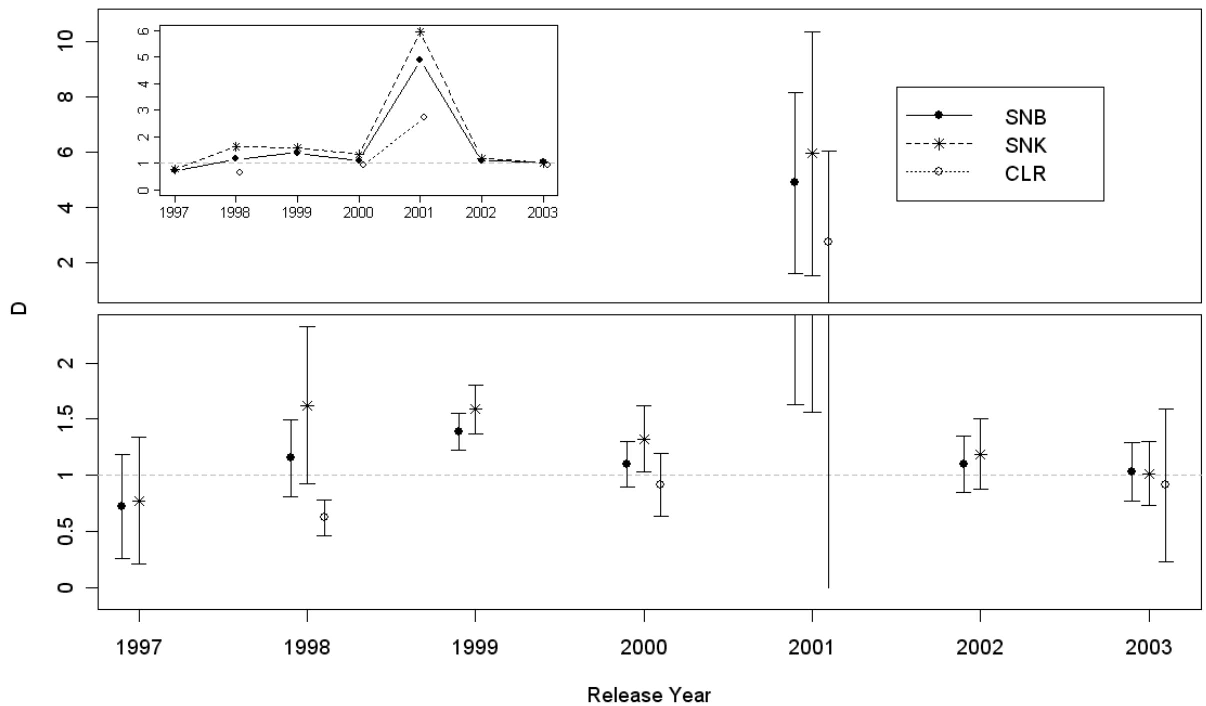


Figure 4.40: Estimated D measure for LGR ($\widehat{D_{LGR}}$) for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at $D = 1$. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish were not calculated in 1997, 1999, and 2002 because too few tagged Clearwater spring Chinook were transported from Lower Granite in those years.

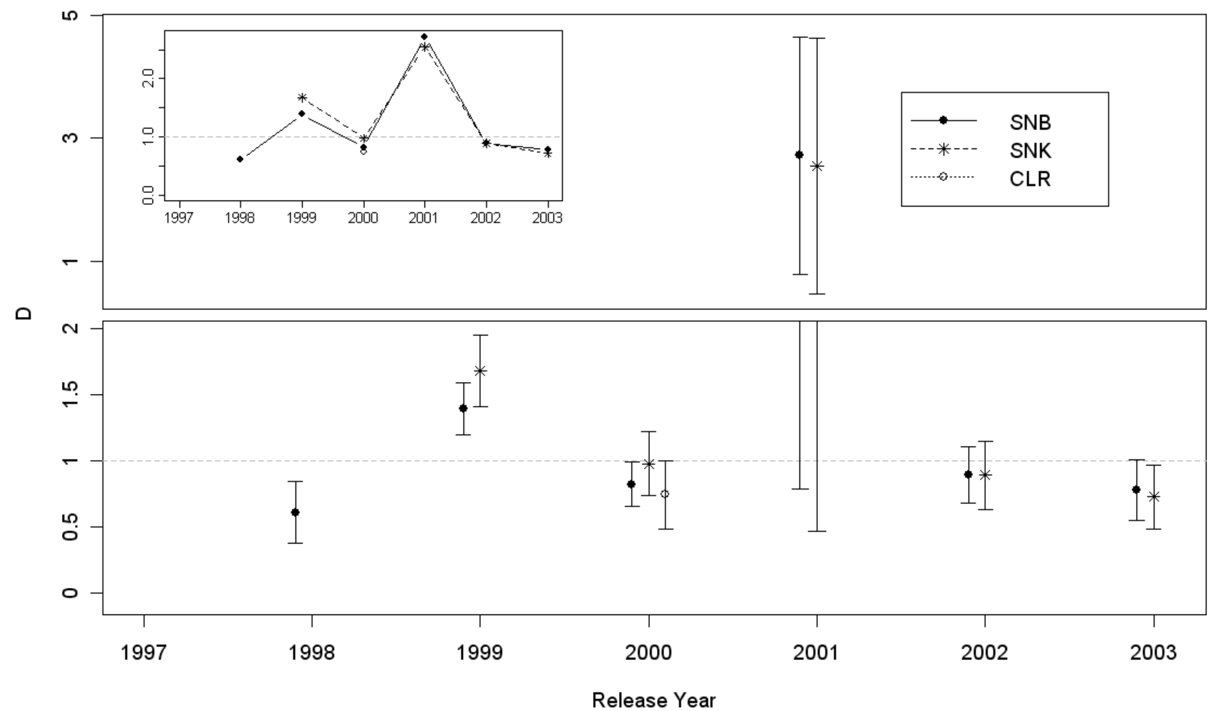


Figure 4.41: Estimated D for LGS ($\widehat{D_{LGS}}$) for spring Chinook salmon, with 95% confidence intervals. The lower, upper, and inset plots have different scales on the vertical axis. The upper plot shows the 2001 estimate and confidence interval apart from other release years. Confidence intervals are omitted from the inset plot. The horizontal lines are at $D = 1$. Estimates do not include jacks. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater. Estimates for Clearwater (CLR) fish are available only in 2000 because too few tagged Clearwater spring Chinook were transported from Little Goose in other years.

4.7.2 Hatchery Summer Chinook Salmon

Estimates of systemwide D measures (D_{SYS} and D^U_{SYS}) for summer Chinook salmon were based on transportation from Lower Granite for the 1997, 1998, 2000, and 2003 release years, and on transportation from Little Goose for the 1999 release year. No estimate of D was available for the 2001 release year for summer Chinook because too few nontransported fish from that release group were detected as adults, and so the full ROSTER model could not be used, and in particular, the estimate of juvenile inriver survival necessary to compute D estimates was unavailable. For the release years with estimates, only a single transport dam was analyzed in any given release year, resulting in identical estimates of the tagged and untagged systemwide D measures (i.e., $D_{SYS} = D^U_{SYS}$ for summer Chinook for these release years; Figure 4.42; Tables G.19 and G.20). Additionally, for years in which only Lower Granite transport groups are analyzed, the systemwide D measure will be equal to the dam-specific D measure for Lower Granite: $D_{SYS} = D_{LGR}$ for the 1997, 1998, 2000, and 2003 release years for summer Chinook. Similarly, because only Little Goose transportation is analyzed for the 2000 summer Chinook release year, $D_{SYS} = D_{LGS}$ for 1999. For these reasons, it is more useful to consider the dam-specific results than the systemwide results.

Estimates of the dam-specific D measure for Lower Granite ($\widehat{D_{LGR}}$) for summer Chinook ranged from 0.99 ($\widehat{SE} = 0.37$) for the 1997 release group to 2.73 ($\widehat{SE} = 0.70$) for the 1998 release group, and averaged 1.48 ($\widehat{SE} = 0.32$) over the release years 1997, 1998, 2000, and 2003 (Figure 4.43; Table G.21; Table 4.2). The estimate of D_{LGR} for summer Chinook was significantly greater than 1.0 (at the 10% significance level) for the 1998 and 2000 release groups, but not for the 1997 or 2003 release groups. The single estimate of the dam-specific D measure for Little Goose ($\widehat{D_{LGS}}$) for summer Chinook was $\widehat{D_{LGS}} = 0.85$ ($\widehat{SE} = 0.10$) for the 1999 release group. These estimates do not include jacks. Results including jacks are available at `http://www.cbr.washington.edu/trends/roster.php`.

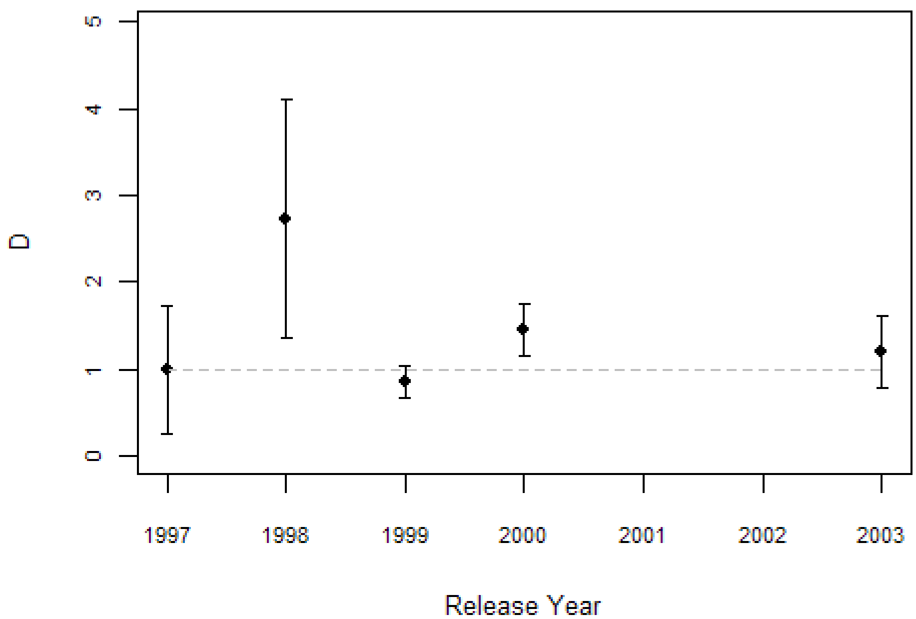


Figure 4.42: Estimated tagged systemwide D measure ($\widehat{D_{SYS}}$) for summer Chinook salmon, with 95% confidence intervals. Untagged systemwide D estimates ($\widehat{D^U_{SYS}}$) are identical for summer Chinook. The horizontal line is at $D = 1$. Estimates do not include jacks. No estimate is available for the 2001 release group because too few nontransported adults were detected from that release group to use the full ROSTER model. No estimate is available for the 2002 release year because too few tagged summer Chinook were transported at any transport dam in that year.

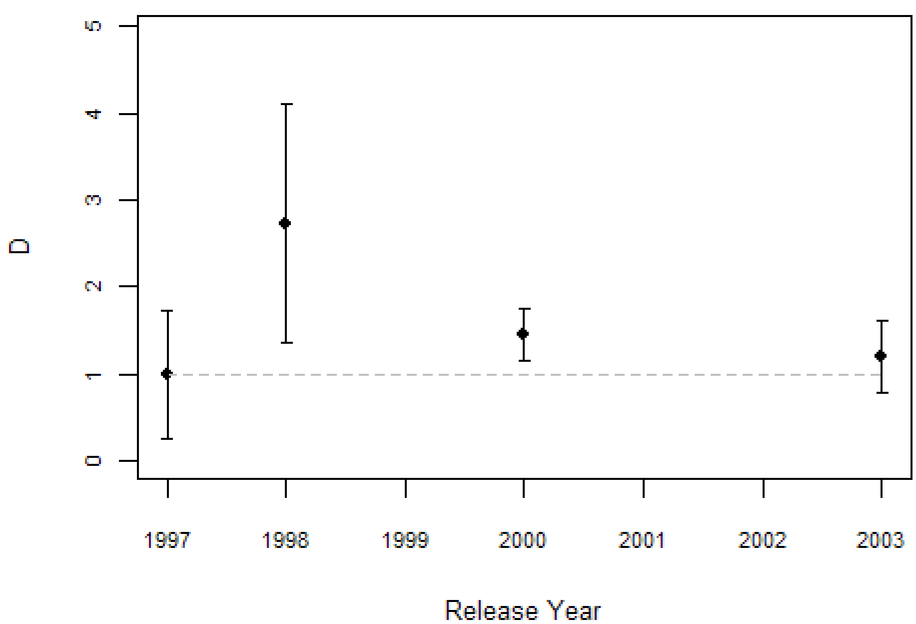


Figure 4.43: Estimated D for LGR for summer Chinook salmon ($\widehat{D_{LGR}}$), with 95% confidence intervals. The horizontal line is at $D = 1$. Estimates do not include jacks. Estimates were not calculated for the 1999 and 2002 release years because too few tagged summer Chinook were transported from Lower Granite in those years to analyze LGR-transport groups. No estimate is available for the 2001 release year because too few nontransported adults were detected from that release group to use the full ROSTER model.

4.7.3 D Summary

Table 4.2 summarizes the D results for spring and summer Chinook salmon. Results are classified by project, where "System" represents the systemwide D (D_{SYS}). For each project, run (spring or summer), and release area, the average observed measure is presented with and without 2001 data, and the measure for 2001 is shown separately. The average is the geometric mean. Also, the one-tailed P-value from the meta analysis testing whether the D measure is greater than 1.0 is shown. Only results for the tagged release group are shown; the untagged D measure (D^U_{SYS}) is omitted. Except for spring Chinook from the Clearwater River, most D estimates are significantly greater than 1.0.

Table 4.2: Summary table of D results for tagged spring and summer Chinook. Project = "System" represents D_{SYS}. Average is geometric mean. Values in parentheses are the standard errors of the point estimates to the left. The one-tailed P-value is from meta analysis testing if the D measure is greater than 1.0. D was not calculated for 2001 for summer Chinook because of limitations of the data.

			Average D			
		Release	**Including**	**Excluding**	**Only**	**1-Tailed**
Project	**Run**	**Area**	2001	2001	2001	**P-value**
System	Spring	CLR	1.0736 (0.3476)	0.7851 (0.0922)	2.7447 (1.6765)	0.5412
LGR	Spring	CLR	1.0928 (0.3497)	0.8040 (0.1026)	2.7447 (1.6765)	0.4595
LGS	Spring	CLR	0.7398 (-)	0.7398 (-)	NA (-)	0.9567
System	Spring	SNK	1.4368 (0.3473)	1.1550 (0.1418)	5.3236 (2.0028)	< 0.0001
LGR	Spring	SNK	1.5233 (0.3770)	1.2134 (0.1401)	5.9617 (2.2444)	< 0.0001
LGS	Spring	SNK	1.2173 (0.2810)	1.0123 (0.1817)	2.5445 (1.0616)	< 0.0001
System	Spring	SNB	1.2398 (0.2801)	1.0008 (0.0854)	4.4801 (1.5212)	< 0.0001
LGR	Spring	SNB	1.3232 (0.3049)	1.0638 (0.0933)	4.8998 (1.6676)	< 0.0001
LGS	Spring	SNB	1.0444 (0.2308)	0.8624 (0.1165)	2.7202 (0.9878)	0.0002
System	Summer	SNB	1.3232 (0.2672)	1.3232 (0.2672)	NA (-)	< 0.0001
LGR	Summer	SNB	1.4765 (0.3232)	1.4765 (0.3232)	NA (-)	< 0.0001
LGS	Summer	SNB	0.8536 (-)	0.8536 (-)	NA (-)	0.9158

4.8 Goodness-of-Fit

A comparison was made between the SAR for each release group estimated by the ROSTER model (Section 4.1) to the estimated heuristic SAR measure that does not distinguish between transported and nontransported fish (Eq. (E.28)). Figure 4.44 shows the relationship between these two estimates for all release groups combined, demonstrating a very high level of correlation between the two estimates ($r^2 = 0.9918$). This result suggests that the ROSTER model is correctly analyzing the individual capture histories to reconstruct overall SAR values, and that the ROSTER model adequately fits the release-recapture data. The advantage of using Program ROSTER over simpler heuristic analyses is that Program ROSTER provides estimates of ocean survival, T/I ratios, and differential mortality, as well as several measures of perceived adult upriver survival.

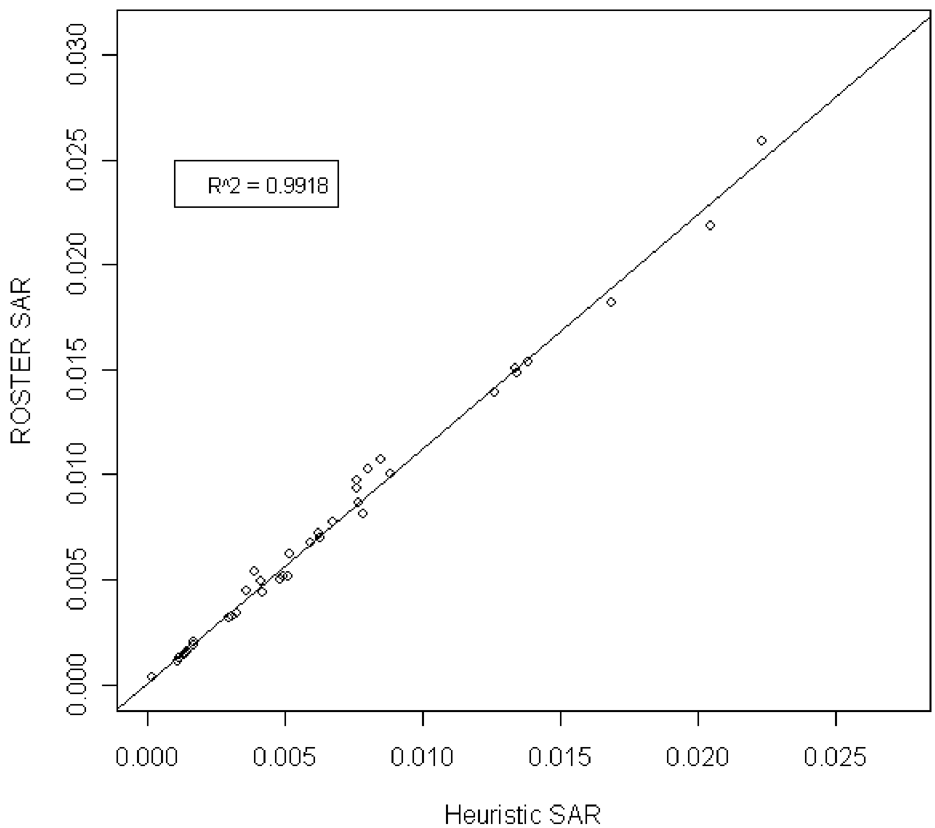


Figure 4.44: Comparison of overall SAR estimated by the ROSTER model versus a heuristic overall SAR. Age-1-ocean steelhead are included in SAR estimates, but age-1-ocean Chinook are excluded. Regression line shown.

Chapter 5

Discussion

This report presents an analysis of survival and transportation effect estimates for hatchery spring and summer Chinook salmon and steelhead from the Snake River Basin released as smolts from 1996 through 2003. The analysis approach used here differs from alternative methods by using a comprehensive maximum likelihood modeling approach in the form of a migratory life-cycle model, the ROSTER model. This approach integrates all information provided by tagged fish throughout their entire migration through the hydrosystem, including data from both the juvenile and the adult migrations. By modeling the migratory paths that produce the detection histories, the ROSTER model connects the juvenile and adult life stages in a biologically reasonable way that recognizes that the same fish produce both sets of data. Additionally, this comprehensive modeling approach incorporates the multiplicative transportation effects (i.e., T/I parameters) directly into the model. The result is that all parameter estimators, including estimators of SAR, T/I and D, are maximum likelihood estimators (MLEs) with well-known statistical properties (reviewed in Norden 1972, 1973).

There are both similarities and differences between the modeling approach used here and the alternative approaches used by the National Marine Fisheries Service (NMFS) and the Comparative Survival Study (CSS). Both the NMFS method (Sandford and Smith 2002), and the CSS method (Berggren et al. 2007), model the juvenile migration and use simple counts of returning adults to estimate T/I and D. Unlike Program ROSTER, they do not model ocean and adult survival. Nevertheless, all three analysis methods (Program ROSTER, NMFS, and CSS) used to estimate T/I and D for a given release group rely on the same set of PIT-tag detection data to estimate juvenile survival and transportation effects. The comprehensive likelihood model approach in Program ROSTER explicitly recognizes that fact, and models the resulting correlation between survival and transportation effect parameters to derive appropriate measures of uncertainty for estimates of performance measures. Estimates of this correlation are unavailable if survival and transportation effects are estimated in a piecemeal fashion. Program ROSTER also makes it easy to explore alternative hypotheses concerning the effects of transportation on adult returns by allowing the user to look at alternative model parameterizations.

All analysis methods reply on assumptions. Because Program ROSTER models ocean and adult survival and detection, it incorporates more assumptions than do the NMFS and CSS methods. However, most of the assumptions relate to the juvenile migration and are shared by all three methods. In particular, all three methods rely on the CJS assumptions of homogeneous juvenile survival and detection probabilities across the release group, with no effect of detection on future juvenile survival and detection probabilities. The ROSTER model extends these assumptions to the ocean and migratory adult life stages, allowing for effects of juvenile transportation throughout those life stages. Violations of assumptions relating to the migratory juvenile life stage will affect results from all three methods. The goodness-of-fit plot in this report (Figure 4.44) suggests that the ROSTER model accurately estimated SAR for the release groups analyzed here. A more formal goodness-of-fit test carried out in Buchanan and Skalski (2007) indicated an acceptable degree of fit for at least one of the release groups analyzed here (2000 release group of summer Chinook salmon). Thus, while more exploration of the effects of assumption violations should be performed, the ROSTER model appears to adequately fit the data.

The joining of the juvenile and adult life stages in the ROSTER model means that Program ROSTER requires larger sample sizes than do alternative methods that model only the juvenile migration. In particular, Program ROSTER requires release groups large enough to observe adult detections across the returning age classes. Low ocean return probabilities mean that release groups smaller than 50,000 tagged fish are unlikely to yield sufficient data to estimate transportation parameters. Thus, PIT-tag releases need to be pooled to obtain sufficient sample size, as done in this report. In addition, the ROSTER model requires transport groups of sufficient size in order to estimate transportation effects. This is because transportation effects on the adult upriver migration are parameterized on an age-specific basis in the model. Other approaches either have the same requirement, or else ignore age-specific effects. In this report, the minimum transport group analyzed was 5,000 smolts. The group of nontransported fish that pass Bonneville must also be sufficiently large (e.g., $\geq 5,000$) in order to estimate the ocean return probabilities of this group of fish. This requirement can make the ROSTER model difficult to fit for release years such as 2001, when the vast majority of smolts that survived to Bonneville arrived there on barges, with very few smolts surviving inriver. These data requirements of Program ROSTER mean that the estimated performance measures necessarily reflect annual values over a large segment of fish populations.

In addition to differences in estimation methods and required sample sizes, the definitions of the T/I and D measures estimated by Program ROSTER differ from both those estimated by NMFS and those estimated by the CSS. All T/I and D measures compare the SAR of transported smolts to the SAR of a nontransported control group. In Program ROSTER, the transport group and the control group represent two different management strategies for the hydrosystem. The transported smolts represent the strategy that includes operating the juvenile bypass and transportation systems as they were operated during the release group's outmigration. The ROSTER model parameterizes transportation effects relative to the survival of all nontransported fish, and thus uses all nontransported fish in the control group, including both detected and nondetected fish. This means that the control group used by Program ROSTER represents a management strategy that does not include the transportation system (because control fish are not transported), but does include operation of the juvenile bypass system as operated during the release group's outmigration. The NMFS and CSS T/I and D measures, while different from each other, both restrict the control group to fish that were neither transported nor detected at transport dams. These control fish represent a hydrosystem with neither transportation nor juvenile bypass to avoid turbine passage. This means that the transportation effect measures estimated by Program ROSTER and the measures estimated by NMFS and CSS are inherently different, because they use different control groups and thus gauge transportation against different management strategies.

If undetected fish have higher survival than detected (i.e., bypassed) fish, either because of an inherent size-selectivity of the detection system (Zabel et al. 2005) or because of a detection effect on survival (as suggested by Bouwes et al. 1999), then estimates of T/I and D based on a nondetected control group are expected to be lower than estimates of T/I and D based on a control group that includes detected fish. Thus, based on observations that detected fish have lower SAR than nondetected fish (e.g., Sandford and Smith 2002; Smith et al. 2006), estimates of T/I and D from Program ROSTER may be expected to be higher than estimates from NMFS and CSS. This was generally observed to be the case in our analyses

The reasoning behind the NMFS and CSS restriction of the control group to nondetected smolts is that nondetected smolts have passage histories that most closely mimic those of untagged smolts, because in general all untagged smolts are transported from the first transport dam where they enter the juvenile bypass system. Program ROSTER uses a different approach to make inference to untagged smolts, using the "untagged" performance measures R^U_{SYS}, D^U_{SYS}, and SAR^U. These measures are estimated using survival and transportation effect parameters estimated from tagged smolts, but also use the assumption that all smolts that enter the juvenile bypass system at a transport dam are transported. Direct inference from estimates of these untagged performance measures is to the tagged release group, had its members been treated as untagged fish at the transport dams (i.e., all transported upon detection). Further inference to the untagged run-at-large is contingent on how well the release group represents the untagged population in terms of survival and reaction to transportation; this concern affects all performance measure estimates based on tagging data, including the NMFS and CSS estimates as well as those from Program ROSTER. Possible tagging effects and tag loss must also be considered when making inference to untagged fish. Tagging effects will influence SAR estimates more than estimates of T/I or D, as discussed later in this chapter.

Another possible difference between the Program ROSTER transportation effect measures and the NMFS and CSS measures is introduced by the requirement of large transport groups for the ROSTER model. This requirement restricts the estimation of transportation effects to dams where sufficient numbers of tagged smolts were transported during the release year. Any incidental transportation is not represented by the performance measures. For this report, the minimum transport group size was set at 5,000, in order to ensure enough returning transported adults to estimate transportation effects with reasonable precision. Only Lower Granite and Little Goose dams had tagged transport groups of at least 5,000 in general, and in some years, only one of these two dams had sufficient transportation. Thus, inference from the systemwide T/I and D performance measures reported here is limited to Lower Granite or Little Goose transportation, or both, depending on the release group; transportation operations at Lower Monumental (and McNary) are not represented by these results. Inference is to the dams where sufficient tagged smolts were actually transported during the release year, rather than to all dams where any transportation may have occurred. Estimates of transportation effect measures from NMFS and CSS generally include transportation from each of Lower Granite, Little Goose, and Lower Monumental dams. Thus, inference from Program ROSTER is generally to fewer transport dams than from NMFS and CSS estimates. Additionally, it has been noted by Bouwes et al. (1999) and Williams et al. (2005) that D and T/I estimates tend to be higher for Lower Granite and Little Goose transportation than for Lower Monumental and McNary transportation. This means that systemwide D and T/I measures that represent transportation from all transport dams will tend to be inherently lower than systemwide D and T/I measures that represent transportation from only the upstream dams. Because NMFS and CSS estimates incorporate Lower Monumental transportation as well as Lower Granite and Little Goose transportation, it is expected that their estimates will be lower than the systemwide estimates presented in this report, which are based on transportation at only Lower Granite and/or Little Goose. However, the difference should be small because relatively few fish are transported at the downstream dams.

There are several other reasons why comparing estimates of D from different investigators may be problematic. First, estimates in this report are for hatchery fish only, and Williams et al. (2005) reported results for wild and hatchery fish combined. Anderson et al. (2005) reported different patterns of SAR (and consequently, D) among wild and hatchery yearling Chinook. Second, Bouwes et al. (1999) reported that estimates of D are influenced by the method used to extrapolate juvenile inriver survival to Bonneville in early years before PIT-tag detection was available there. However, only a few estimates of D presented in this report rely on extrapolation of juvenile inriver survival: the 1997 release group of spring Chinook salmon (release area SNB), and the 1998 release group of summer Chinook salmon. Both were extrapolated on a per-detection site basis, based on goodness-of-fit tests comparing per-site, per-project, and per-river kilometer extrapolation methods.

Given the above caveats on comparisons of D estimates across sources, the dam-specific D estimates reported here may be compared to dam-specific estimates of D from NMFS and CSS. Also, the untagged systemwide estimates ($\widehat{D^U_{SYS}}$) may be compared to systemwide estimates from NMFS and CSS. For pooled wild and hatchery spring and summer Chinook salmon, the mean systemwide D estimate reported by Williams et al. (2005) was 0.72 over the release years 1997 to

2000. For hatchery spring Chinook salmon, the mean systemwide D estimate reported by Berggren et al. (2007) ranged from 0.57 to 0.79 for the same release years, while the mean systemwide D estimate for hatchery summer Chinook salmon ranged from 0.77 to 0.95. Our mean estimate of D^U_{SYS} for the release years from 1997 to 2000 ranged from 0.73 ($\widehat{SE} = 0.12$) for Clearwater hatchery spring Chinook to 1.36 ($\widehat{SE} = 0.35$) for hatchery summer Chinook. Our estimate for Clearwater spring Chinook was similar to the NMFS and CSS estimates (but it was based on only two release years because of low transport numbers), but our estimates for other release groups of yearling Chinook were generally higher than the NMFS and CSS estimates. The difference in the control groups and the exclusion of Lower Monumental dam (where too few tagged smolts were transported; Figures 3.6 to 3.10) at least partially explain why NMFS estimates (from Williams et al. 2005) and CSS estimates (from Berggren et al. 2007) are consistently lower than our estimates for the same release years. The stock composition of the release groups may also contribute to the observed differences.

Another possible reason behind differences in D estimates is the methods used to estimate juvenile inriver survival (S_J), as indicated above. Lower inriver survival estimates will produce lower estimates of D. We compared our estimates of S_J, computed using Program ROSTER, to the NMFS estimates reported in Williams et al. (2005). NMFS estimates of juvenile inriver survival from Lower Granite to Bonneville are available for yearling hatchery and wild Chinook (pooled) from the Snake River for release years 1999 to 2003. The NMFS estimates ranged from 0.279 ($\widehat{SE} = 0.016$) for 2001 to 0.578 ($\widehat{SE} = 0.060$) for 2002, with a mean of 0.486 (including the 2001 release group). Over the same release years, Program ROSTER estimates of S_J for hatchery spring Chinook salmon from the Snake River Basin (release area SNB) ranged from 0.3554 ($\widehat{SE} = 0.0997$) for the 2001 release group to 0.7314 ($\widehat{SE} = 0.0470$) for the 2002 release group, with a mean estimate of 0.6100 ($\widehat{SE} = 0.0686$; Table G.3). For hatchery summer Chinook salmon released in the Snake River Basin from 1999 to 2003 (excluding 2001 when no S_J estimate was available), Program ROSTER estimates of S_J ranged from 0.5184 ($\widehat{SE} = 0.0400$) for the 1999 release group to 0.6771 ($\widehat{SE} = 0.0799$) for the 2003 release group, with a mean estimate of 0.6127 ($\widehat{SE} = 0.0348$; Table G.3). The NMFS estimates were generally lower than our estimates for both spring and summer Chinook salmon. Estimates of juvenile inriver survival from Lower Granite to Bonneville for hatchery steelhead are available from both Williams et al. (2005) and Program ROSTER for release years 1997, 1999, 2000, 2002, and 2003. NMFS estimates over these years ranged from 0.262 ($\widehat{SE} = 0.050$) for the 2002 release group to 0.474 ($\widehat{SE} = 0.069$) for the 1997 release group, with a mean estimate of 0.376. Program ROSTER estimates of S_J over the same release years ranged from 0.2387 ($\widehat{SE} = 0.0245$) for the 2000 release group to 0.4787 ($\widehat{SE} = 0.0656$) for the 1999 release group, with a mean estimate of 0.3726 ($\widehat{SE} = 0.0455$; Table G.3).

Estimates of yearling Chinook juvenile inriver survival in this report are generally greater than analogous estimates from NMFS (Williams et al. 2005). The NMFS Chinook estimates of juvenile inriver survival are for spring and summer hatchery and wild Chinook combined, whereas our estimates (Table G.3) are reported separately for hatchery spring and summer Chinook salmon. Both Program ROSTER and NMFS use the CJS model to estimate survival to Bonneville. Program ROSTER estimates a single annual estimate, while NMFS estimates a weighted average of daily or weekly survival estimates. Additionally, Program ROSTER uses adult detection data at the dams to estimate juvenile inriver survival (S_J), while NMFS instead uses detection data from the estuary towed PIT-tag detection array. We compared estimates of S_J using adult detections to estimates of S_J using towed array detections for the Snake River Basin spring Chinook release groups analyzed in this report (Figure 5.1), and found the two sets of estimates to be comparable. Thus, differences in S_J estimates between NMFS and Program ROSTER are more likely caused by differences in release groups or differences in the temporal approach (i.e., a pooled annual estimate or a weighted average of weekly estimates) than by differences resulting from the use of adult detection data in place of estuary detection data.

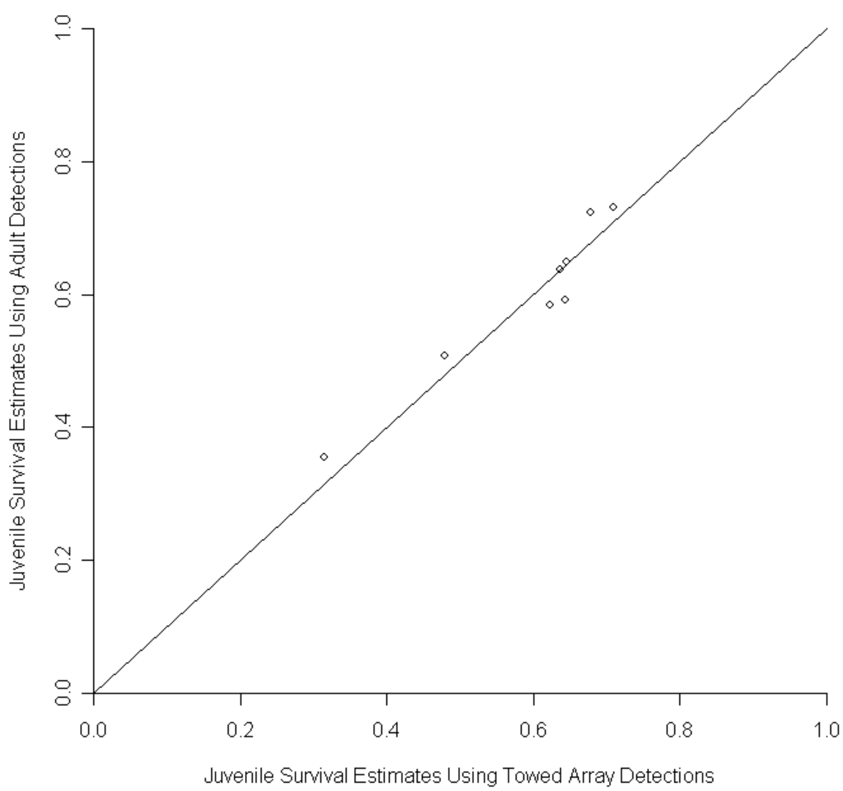


Figure 5.1: Estimates of juvenile inriver survival (S_J) for spring Chinook salmon from the Snake River Basin (release area SNB), estimated using detections of returning adults (vertical axis) versus using detections from the towed estuary PIT-tag detection array (horizontal axis). The line is the 45-degree line through the origin.

All estimates of SAR based on PIT-tag data assume that PIT tags have no effect on survival, and that there is no tag loss. Feasibility studies for using PIT tags to study migrating salmonids in the Columbia River Basin conducted in the 1980s concluded that PIT tags have minimal effect on longterm survival (Prentice et al. 1990), and results from PIT-tag studies have been used to monitor populations for a decade. However, there is some evidence that PIT-tagged fish have lower survival than untagged fish. Williams et al. (2005) compared SAR estimates from untagged wild Chinook and steelhead to SAR estimates based on tagged fish, and found that the estimates from untagged fish were generally higher than from tagged fish. It is not clear how much of the difference might be explained by harvest or tag loss. Williams et al. (2005) reported no difference between tagged and untagged SAR estimates for hatchery Chinook. Brakensiek and Hankin (2007) found that PIT-tagging juvenile coho salmon lowers their survival at least temporarily, to an extent that could not be explained by tag loss.

Prentice et al. (1994) also studied the effects of PIT-tagging on coho. They concluded that there was significant tag loss after release of tagged juveniles, leading to lower SAR estimates from PIT-tagged data than from coded wire tag (CWT) data. When PIT-tag-based SAR estimates were corrected for tag loss, there was no difference between the PIT-tag and CWT-based SAR estimates. They also determined that most tag loss occurred during late maturation, rather than soon after release. Additionally, there has been observation of significant loss of PIT tags ($> 15\%$) from hatchery spring Chinook salmon from the Yakima River (Curtis Knudsen, personal communication).

Whether PIT tags affect survival or are lost at sufficient rates to lower the estimated SAR of tagged fish, it appears that SAR, juvenile inriver survival, and possibly ocean survival estimated from PIT-tag detection data may be seriously negatively biased. Thus, estimates of SAR based on PIT tags should be used with caution when comparing to the 2-4% recovery goal outlined by the NPCC (2003), or to assess the status of populations. On the other hand, performance measures such as T/I and D, which are ratios of tag returns, should be unaffected by tag loss, as long as loss rates for nontransported and transported fish are equal. More explorations into the effect of PIT tags on long-term survival and the degree of tag loss are needed in order to fully interpret SAR estimates derived from PIT-tag data.

Chapter 6

Conclusions

The release-recapture model behind Program ROSTER represents the migratory portion (both juvenile and adult) of the life cycle of spring and summer Chinook salmon and steelhead in the Columbia and Snake river basins. Using a life-cycle modeling approach connects juvenile and adult detection data in a biologically reasonable way, and thus avoids model misspecification that may result from separate single life-stage models. The ROSTER model provides estimates of quantities (e.g., ocean return probabilities) that are not directly estimable if juvenile and adult stages are analyzed separately. Finally, the life-cycle modeling approach provides a context for defining performance measures such as SAR and T/I ratios, along with easily computed maximum likelihood estimates and variance estimates. By dividing the analysis approach into a model-fitting stage and a separate stage for estimating performance measures, issues of statistical methodology are clarified, and defining and estimating performance measures is made clear and flexible.

The statistical modeling approach behind Program ROSTER is capable of monitoring and evaluating Columbia River Basin salmonids, as long as sufficient numbers of PIT-tagged smolts are released annually. Program ROSTER provides estimates of annual SAR, juvenile inriver survival, ocean survival, and adult survival, as well as transportation effects estimated on several spatial scales. Due to the high data requirements of Program ROSTER, dictated by low ocean return rates, estimates reflect large-scale processes that complement alternative smaller-scale analyses.

Program ROSTER analyzes transportation effects from those dams that had sufficient numbers of transported tagged smolts. For these dams, it is unnecessary to perform formal and expensive paired-release studies to analyze transportation effects. Instead, PIT-tag data from run-of-river tagged smolts are sufficient, when combined with information on transport operations at the dams. Dams with low numbers of transported smolts, however, cannot be analyzed using Program ROSTER because numbers of adult returns by age class are too few. Estimation approaches which ignore age-specific return information can cope with fewer return numbers. For dams with low transport numbers (e.g., Lower Monumental and McNary), dam-specific transport studies are still needed in order to transport sufficient numbers of smolts to make estimation of transportation effects feasible.

The results presented in this report (summarized in Table 6.1) indicate that in most years from 1997 to 2003, transportation from Lower Granite and Little Goose dams resulted in higher adult returns for hatchery spring and summer Chinook salmon from the Snake River Basin. The geometric average T/I for Lower Granite was 1.64 ($\widehat{SE} = 0.08$) for spring Chinook salmon from the Snake River Basin (release years 1997 to 2003, excluding 2001), and 2.12 ($\widehat{SE} = 0.45$) for summer Chinook salmon (release years 1997, 1998, 2000, 2003). For Little Goose transportation, the geometric average T/I for spring Chinook was 1.16 ($\widehat{SE} = 0.12$; release years 1998 to 2003, excluding 2001), and the single estimate for summer Chinook was 1.38 ($\widehat{SE} = 0.12$) for the 1999 release group. Too few tagged hatchery steelhead were transported from any dam to estimate transportation effects. For most Chinook release groups, estimates of D were greater than 1, indicating that Chinook transported from Lower Granite and Little Goose had higher post-Bonneville survival than nontransported fish. Even in cases where the estimate of D was less than 1, adult returns from the transport dam were higher for transported fish than for nontransported fish. Some transported adult Chinook experienced lower survival from Bonneville to Lower Granite than nontransported adults. Nevertheless, transported smolts generally returned as adults in higher proportions than nontransported smolts (Table 6.1). Despite the transportation program, however, SARs of the entire release group from Lower Granite to Lower Granite were often less than the 2% minimum recommended by the NPCC for population recovery (NPCC 2003), for both Chinook and steelhead (Table 6.1).

For hatchery spring and summer Chinook, approximately 86% of the mortality between passing Lower Granite as a smolt and returning to Lower Granite as an adult occurred between Bonneville and Bonneville. For hatchery steelhead, the percentage was 74%. With the average ocean return probability equal to 1.24% ($\widehat{SE} = 0.42\%$; Table 6.1) for nontransported spring Chinook from the Snake River Basin for release years 1999 to 2003, it is not possible for nontransported Snake River spring Chinook to achieve the goal of 2% SARs. Average ocean return probabilities for nontransported summer Chinook and steelhead were higher (2.77%, $\widehat{SE} = 0.90\%$ for summer Chinook, and 2.80%, $\widehat{SE} = 0.87\%$ for steelhead; Table 6.1), but did not include the 2001 release group, which had a much lower ocean return probability. Thus, the ocean return probability contributes heavily to mortality of migrating salmonids. This indicates that additional research is needed to identify mortality sources operating in the estuary and ocean life stages of Columbia River Basin salmonids. Additionally, more research is needed on the effects of PIT tags on long-term survival of Columbia and Snake River salmonids, and on the possibility and prevalence of tag loss that might bias estimates of SAR.

Table 6.1: Summary table of results. Average SAR is the arithmetic mean of the estimated smolt-to-adult return ratio for the tagged release group (SAR), including both transported and nontransported fish. Average ocean return probability is the arithmetic mean of the estimated survival from Bonneville to Bonneville for nontransported fish. Average T/I and D are the geometric means of the estimated systemwide measures for the tagged release groups, R_{SYS} and D_{SYS} respectively, combining transportation effects from all analyzed transport dams. Only dams with at least 5,000 tagged smolts transported in a given year were analyzed; transportation effect estimates are restricted to Lower Granite, Little Goose, or both. P-values are shown from one-tailed tests of the alternative hypotheses listed for T/I, D, and adult survival. The T/I and D tests are meta-analyses comparing average R_{SYS} and D_{SYS} to 1.0, and the adult survival test assess whether overall adult survival from Bonneville to Lower Granite was lower for LGR-transport fish compared to nontransported fish. Values in parentheses are the standard errors of the point estimates above. Chinook measures do not include the age-1-ocean age class ("jacks"), while steelhead measures do include the age-1-ocean age class.

	SAR (SAR)	**Ocean Return** (O_{NT})	**T/I** (R_{SYS})		***D*** (D_{SYS})		**Adult Survival**
Stock	**Average**	**Average**	**Average**	$H_A : R > 1$	**Average**	$H_A : D > 1$	$H_A : S_{A_{LGR}} < S_{A_{NT}}$
CLR Spring Chinook	0.0055	0.0122	1.4884	< 0.0001	1.0736	0.5412	0.0928
	(0.0015)	(0.0048)	(0.4789)		(0.3476)		
SNK Spring Chinook	0.0078	0.0128	1.5501	< 0.0001	1.4368	< 0.0001	0.0372
	(0.0021)	(0.0042)	(0.3821)		(0.3473)		
SNB Spring Chinook	0.0071	0.0124	1.4654	< 0.0001	1.2398	< 0.0001	0.0163
	(0.0018)	(0.0042)	(0.3518)		(0.2801)		
Summer Chinook	0.0115	0.0277	1.8897	< 0.0001	1.3232	< 0.0001	0.1916
	(0.0031)	(0.0090)	(0.7601)		(0.2672)		
Steelhead	0.0045	0.0280	-	-	-	-	-
	(0.0011)	(0.0087)	-	-	-	-	-

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Appendix A

Glossary

ADULT: Returning migrant. In general, any fish that is detected moving upstream after the presumed outmigration year. Includes age-1-ocean fish.

ADULT AGE CLASS: Category of returning migrants identified by the number of winters spent in the ocean. Ignores number of years spent in freshwater before juvenile outmigration. Also referred to as "ocean age class."

ADULT UPRIVER SURVIVAL: S_A; see Perceived Adult Upriver Survival.

ADULT UPRIVER SURVIVAL BY RELEASE GROUP: $S_{A_{Rel}}$, average perceived adult upriver survival for tagged fish in a given release group. Combines adult data from multiple return years, and includes both transported and nontransported fish. Includes the age-1-ocean age class for steelhead, but not for Chinook.

ADULT UPRIVER SURVIVAL BY RELEASE GROUP FOR NONTRANSPORTED FISH: $S_{A_{NT}}$, the average perceived adult upriver survival for tagged, nontransported fish in a given release group. Combines adult data from multiple return years, and is restricted to nontransported fish. Includes the age-1-ocean age class for steelhead, but not for Chinook.

ADULT UPRIVER SURVIVAL BY RELEASE GROUP FOR DAM-I TRANSPORT FISH: S_{A_i}, average perceived adult upriver survival for tagged fish from a given release group that were transported from dam i ($i = LGR$ or $i = LGS$). Combines adult data from multiple return years. Excludes the age-1-ocean age class for Chinook; not estimated for steelhead.

ADULT UPRIVER SURVIVAL BY RETURN YEAR: $S_{A_{Ret}}$, average perceived adult upriver survival for tagged adults that are migrating upriver in a given calendar (return) year. Combines adult data from multiple release groups, and includes both transported and nontransported fish. Includes the age-1-ocean age class for steelhead, but not for Chinook.

AGE-J-OCEAN: Classification of returning migrants by the number (J) of winters spent in the ocean.

AGE- AND DAM-SPECIFIC T/I RATIO: R_{ij}, the ratio of the probability of returning from dam i to Bonneville as an age-j-ocean adult for dam-i transport fish to that of fish that were inriver immediately downstream of dam i. R_{ij} isolates the effect of transportation from dam i on age-j-ocean return rates, removing the effect of any transportation from downstream dams on the nontransported (inriver) return probability to Bonneville.

ANNUAL TRANSPORT GROUP: Collection of tagged fish from a single release group that were transported from a particular dam during the release year. Only annual transport groups of at least 5,000 fish are used to estimate transportation effects. Specific to individual dams.

CLR: Clearwater River Basin. One of the three release areas included for spring Chinook salmon.

DAM-SPECIFIC DIFFERENTIAL POST-BONNEVILLE MORTALITY: D_i, the ratio of the SAR from Bonneville to Lower Granite for dam-i transport fish relative to that of nontransported fish. Assumes 98% survival of transport fish during transportation. In general, may include the age-1-ocean age class (jacks); values reported here for Chinook salmon do not include jacks.

DAM-SPECIFIC T/I RATIO: R_i, the ratio of the SAR from dam i to Lower Granite for dam-i transport fish relative to fish that were inriver immediately downstream of dam i. R_i isolates the effect of transportation from dam i on SAR, removing the effect of any transportation from downstream dams on the nontransported (inriver) return probability to Lower Granite. In general, may include the age-1-ocean age class (jacks); values reported here for Chinook salmon do not include jacks.

DETECTION SITE: River location or structure where PIT-tagged fish may be detected. For this report, detection sites are restricted to dams. Classified as "juvenile" or "adult," according to when the tagged fish is detected. All detection coils within a dam are considered to be the same detection site for fish passing in a given life stage (juvenile or adult).

DIFFERENTIAL POST-BONNEVILLE MORTALITY: D, the ratio of SAR from Bonneville to Lower Granite of transported fish to that of non-transported fish. See Dam-Specific Differential Post-Bonneville Mortality and Systemwide Differential Post-Bonneville Mortality.

HEURISTIC PERFORMANCE MEASURES: Performance measure (e.g., SAR, R_i, R_{SYS}, $S_{A_{Rel}}$, and $S_{A_{Ret}}$) that are estimated using recovery ratios and in some cases a reduced set of parameter estimates from the full ROSTER model. Estimated when data sparseness prevents complete analysis using the full ROSTER model.

INRIVER GROUP: Nontransported fish. Includes detected and nondetected tagged fish.

INTEGRATED MORTALITY: For migratory stage i, equal to the negative log of the conditional survival probability through stage i: $\gamma_i = -\ln S_i$.

JACK: For Chinook salmon, a male fish that returns to freshwater after a single winter in the ocean, i.e., an age-1-ocean fish. Not used for steelhead.

JBS: Juvenile Bypass System at a dam.

JUVENILE INRIVER SURVIVAL: S_J, the probability of surviving inriver (nontransported) as a smolt from Lower Granite Dam to Bonneville Dam. Direct inference is to all nontransported, tagged juveniles.

MIGRATION YEAR: Calendar year of smolt outmigration to seawater. Assumed to be the release year for the release groups analyzed in this report.

MINIJACK: Any fish that returns to freshwater to migrate upstream in the same year as its presumed outmigration. Age-0-ocean fish.

NONTRANSPORTED FISH: Any fish from the release group that was not transported as a juvenile.

OCEAN AGE CLASS: See Adult Age Class.

OCEAN RETURN PROBABILITY: The probability of returning to Bonneville as an adult, conditional on reaching Bonneville as a smolt. Estimated separately for nontransported fish (O_{NT}) and for transported fish (O_i for fish transported from dam i, $i = LGR$ or $i = LGS$). Includes survival in the river between Bonneville and the river mouth for both juveniles and adults, in addition to ocean survival. Includes the age-1-ocean age class for steelhead, but not for Chinook.

PERCEIVED ADULT UPRIVER SURVIVAL: Probability of reaching Lower Granite Dam as an adult, conditional on reaching Bonneville Dam as an adult. Includes the joint probability of migrating upriver, surviving, and reascending all dams after any fallback. The complement includes straying, fallback without reascension, natural mortality, and harvest mortality. Also referred to as "adult upriver survival." Includes the age-1-ocean age class for steelhead, but not for Chinook.

PERFORMANCE MEASURE: (1) A number relating to the migration or survival of a particular group of fish; (2) the estimator of that number.

PROPORTION OF TOTAL INTEGRATED MORTALITY: μ_i for migratory stage i, equal to the ratio of the negative log of survival through stage i to the negative log of SAR for nontransported fish. Reflects the relative contribution of stage i to overall mortality compared to other stages, irrespective of the order in which the stages occur.

REACH: Stretch of river or river and ocean between two adjacent detection sites. The “reach” between the juvenile Bonneville detection site and the adult Bonneville detection site includes the ocean.

RELEASE AREA: Geographic region defined by hydrologic units, used to characterize spring Chinook release groups. Release areas are: SNB = Snake River Basin (sum of Snake and Clearwater Rivers); SNK = Snake River (excluding Clearwater); CLR = Clearwater River Basin.

RELEASE GROUP: Collection of fish PIT-tagged and released as smolts within a single calendar year and expected to migrate during the year, for which estimates of performance measures are reported. Restricted to a single species, run (spring or summer), and release area.

RELEASE YEAR: Calendar year during which tagged release group is released as smolts.

RETURN RATE: Probability of returning from an identified juvenile detection site (dam) to an identified adult detection site (dam). Unless otherwise specific, the adult detection site is Lower Granite Dam.

RIGHT-CENSORING: Intentional removal from detection history of any subsequent observations. Applied when fish are treated as known removals at a detection site. A censored detection history is not used to estimate survival over subsequent reaches.

ROSTER: River-Ocean Survival and Transportation Effects Routine. The name of the statistical model and software used to analyze most data sets. The software was developed by the University of Washington and is available at `http://www.cbr.washington.edu/paramest/roster/`.

SITE: Detection site, categorized as either juvenile or adult. Alternatively, location of release of PIT-tagged fish, identified by river kilometer.

SMOLT-TO-ADULT RETURN RATIO: SAR, the probability of returning to Lower Granite Dam as an adult. May be estimated for different treatment groups (e.g., nontransported or transported) and for different initial dams (e.g., probability of returning from Bonneville as a juvenile, or probability of returning from Lower Granite as a juvenile). If not otherwise specified, SAR refers to the entire release group, conditional on reaching Lower Granite as a juvenile. The tagged estimator is SAR, and the untagged estimator is SAR^U. Includes the age-1-ocean age class for steelhead, but not for Chinook.

SNB: Snake River Basin, including the Clearwater Basin. One of the three release areas included for spring Chinook salmon. Is equivalent to the union of CLR and SNK. Also referred to as “Snake River Basin.”

SNK: Snake River Basin, excluding the Clearwater Basin. One of the three release areas included for spring Chinook salmon. Also referred to as “Snake River.”

SYSTEMWIDE DIFFERENTIAL POST-BONNEVILLE MORTALITY: D_{SYS} and D^U_{SYS}, the ratio of the SAR from Bonneville to Lower Granite of all transported fish relative to the SAR of nontransport fish. Incorporates reach-specific juvenile inriver survival, dam-specific T/I ratios, the proportion of fish transported at each transport dam, and the survival of transport fish during transportation (assumed 98%). The tagged measure is D_{SYS}, and the untagged measure is D^U_{SYS}. In general, may include the age-1-ocean age class (jacks); values reported here for Chinook salmon do not include jacks.

SYSTEMWIDE T/I RATIO: R_{SYS} and R^U_{SYS}, the ratio of the SAR from Lower Granite to Lower Granite of the entire release group under the existing transportation system, relative to the expected SAR had there been no transportation. Incorporates both transport and inriver smolts, and any upriver adult effects of juvenile transportation. Depends on dam-specific transportation effects and on the proportion of fish transported at each transport dam. The tagged measure is R_{SYS}, and the untagged measure is R^U_{SYS}. In general, may include the age-1-ocean age class; values reported here for Chinook salmon do not include jacks.

TAGGED PERFORMANCE MEASURE: A performance measure with direct inference limited to the tagged release group, reflecting the transportation probabilities experienced by tagged smolts. Applies to SAR, T/I, and D.

TOTAL INTEGRATED MORTALITY: The negative log of SAR for nontransported fish from Lower Granite to Lower Granite: $\gamma = -\left(\ln S_J + \ln O_{NT} + \ln S_{A_{NT}}\right)$.

TRANSPORT DAM: A dam at which transportation operations occurred during a given release year, such that 5,000 or more tagged fish of a given release group were transported there during the release year. Designation as "transport dam" is specific to a release group.

TRANSPORT GROUP: The fish from a particular release group that were transported from a particular dam. The dam must be specified. Only transport groups of 5,000 or more fish were analyzed here.

TRANSPORT-INRIVER RATIO: T/I, the ratio of SAR of transported fish (or under the transportation system) to the SAR of nontransported fish (or without the transportation system). See Age- and Dam-Specific T/I Ratio, Dam-Specific T/I Ratio, and Systemwide T/I Ratio.

TRANSPORTATION PROBABILITY: t_i, probability of being transported at dam i, conditional on (1) reaching the dam inriver, (2) being detected there, and (3) not being censored there. Typically differs for tagged and untagged fish.

UNTAGGED PERFORMANCE MEASURE: A performance measure designed for inference to the tagged fish in the release group, had they been treated (i.e., transported) as untagged. Differs from tagged version of performance measure if (1) performance measure depends on transportation probabilities, and (2) tagged and untagged fish are transported in different proportions. Applies to SAR, T/I, and D.

Appendix B

List of Symbols

γ: Total integrated mortality between Lower Granite and Lower Granite for nontransported fish.

γ_A: Integrated mortality through the adult migration from Bonneville to Lower Granite for nontransported fish.

γ_J: Integrated mortality through the juvenile migration from Lower Granite to Bonneville for nontransported fish.

γ_O: Integrated mortality through the ocean life stage from Bonneville to Bonneville for nontransported fish.

$\widehat{\theta}$: The maximum likelihood estimate (MLE) of parameter or performance measure θ.

μ_A: Proportion of total integrated mortality accounted for by the adult migration from Bonneville to Lower Granite for nontransported fish.

μ_J: Proportion of total integrated mortality accounted for by the juvenile migration from Lower Granite to Bonneville for nontransported fish.

μ_O: Proportion of total integrated mortality accounted for by the ocean life stage from Bonneville to Bonneville for nontransported fish.

BON: Bonneville Dam.

CLR: Clearwater River Basin. One of the three release areas included for spring Chinook salmon.

D: Differential Post-Bonneville Mortality.

D_{LGR}: D specific to Lower Granite transportation.

D_{LGS}: D specific to Little Goose transportation.

D_{SYS}: Tagged systemwide D.

D^U_{SYS}: Untagged systemwide D.

JD: John Day Dam.

LGR: Lower Granite Dam.

LGS: Little Goose Dam.

LMO: Lower Monumental Dam.

MCN: McNary Dam.

N: Size of a release group.

O_{LGR}: Ocean return probability from Bonneville back to Bonneville for LGR-transport fish.

O_{LGS}: Ocean return probability from Bonneville back to Bonneville for LGS-transport fish.

O_{NT}: Ocean return probability from Bonneville back to Bonneville for nontransported fish.

R_{LGR}: T/I ratio specific to Lower Granite transportation.

R_{LGS}: T/I ratio specific to Little Goose transportation.

R_{SYS}: Tagged systemwide T/I ratio.

R^U_{SYS}: Untagged systemwide T/I ratio.

S_A: Perceived adult upriver survival.

$S_{A_{LGR}}$: Average perceived adult upriver survival by release group for LGR-transport fish.

$S_{A_{LGS}}$: Average perceived adult upriver survival by release group for LGS-transport fish.

$S_{A_{NT}}$: Average perceived adult upriver survival by release group for nontransported fish.

$S_{A_{REL}}$: Average perceived adult upriver survival by release group.

$S_{A_{RET}}$: Average perceived adult upriver survival by return year.

S_J: Juvenile inriver survival from Lower Granite to Bonneville.

SAR: Smolt-to-adult return ratio (conceptual).

SAR: Tagged SAR measure.

SAR^U: Untagged SAR measure.

SE: Standard error.

SNB: Snake River Basin, including the Clearwater Basin.

SNK: Snake River Basin, excluding the Clearwater Basin.

T/I: Transport-inriver ratio.

Appendix C

Data Collection and Preparation

C.1 Release Sites

Table C.1-C.5 give details of the smaller release groups that comprise the pooled regional release groups used in the analysis. River kilometers (RKMs) from the mouth of the Columbia River are reported using the convention that a dot (.) separates distances on different rivers, with downriver reaches (i.e., higher order streams and rivers) listed first. For example, RKM 522.224.65 represents the North Fork of the Clearwater River, which is located 65 RKM upstream from the confluence of the Clearwater River into the Snake River; the confluence of the Clearwater River is located 224 RKM upstream on the Snake River from the confluence of the Snake River into the Columbia River; and the confluence of the Snake River is located 522 RKM from the mouth of the Columbia River. Thus, to reach the North Fork of the Clearwater River from the mouth of the Columbia River, it is necessary to travel 522 RKM up the Columbia River from its mouth, then 224 RKM up the Snake from the Columbia, and finally 65 RKM up the Clearwater from the Snake. As another example, the Grande Ronde River has RKM address 522.271; to reach the Grande Ronde River from the mouth of the Columbia River, travel 522 RKM up the Columbia to the Snake River, and then 271 RKM up the Snake River to the Grande Ronde River.

Table C.1: Release sites of the spring Chinook salmon release groups from the Clearwater Basin (release area CLR). River kilometer (RKM) is measured from the confluence of the Snake River with the Columbia River (i.e., RKM 522 from the mouth of the Columbia River). Release sites are ordered by total RKM.

Release Year	**Release Site**	**RKM**	**Number Released**	**Percentage**
1996	Powell Rearing Pond	224.120.037.113	11,402	31.3
	Red River Rearing Pond	224.120.101.027	1,212	3.3
	Crooked River Pond	224.120.094.015	2,095	5.8

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1996	Clear Creek	224.120.004	16,464	45.2
	Dworshak NFH (NF Clearwater)	224.065	4,067	11.2
	North Fork Clearwater River	224.065	1,002	2.8
	Other		156	0.4
	Total		36,399	100
1997	Powell Rearing Pond	224.120.037.113	500	2.4
	Red River Rearing Pond	224.120.101.027	500	2.4
	Selway River	224.120.037	1,427	6.9
	Kooskia NFH	224.120.004.001	4,075	19.8
	Dworshak NFH (NF Clearwater)	224.065	14,080	68.4
	Total		20,582	99.9
1998	Powell Rearing Pond	224.120.037.113	1,675	3.2
	Red River Rearing Pond	224.120.101.027	1,000	1.9
	Crooked River Pond	224.120.094.015	499	1.0
	Clear Creek	224.120.004	1,001	1.9
	Dworshak NFH (NF Clearwater)	224.065	47,704	91.4
	Other		306	0.6
	Total		52,185	100
1999	Powell Rearing Pond	224.120.037.113	1,000	1.8
	Papoose Creek	224.120.037.105	749	1.4
	Newsome Creek	224.120.084	999	1.8
	Meadow Creek, Selway River	224.120.037.031	999	1.8
	Clear Creek	224.120.004	1,001	1.8
	Lolo Creek	224.087	1,010	1.8
	Dworshak NFH (NF Clearwater)	224.065	47,845	86.9
	Other		1,478	2.6
	Total		55,081	99.9
2000	Kooskia NFH	224.120.004.001	746	1.5
	Clear Creek	224.120.004	750	1.5
	Dworshak NFH (NF Clearwater)	224.065	47,745	94.8

Table C.1 (continued)

Release Year	**Release Site**	**RKM**	**Number Released**	**Percentage**
2000	Other		1,125	2.3
	Total		50,366	100.1
2001	Powell Rearing Pond	224.120.037.113	997	1.7
	Newsome Creek	224.120.084	1,063	1.8
	Kooskia NFH	224.120.004.001	750	1.3
	Lolo Creek	224.087	1,070	1.8
	Dworshak NFH (MS Clearwater)	224.065	51,196	86.0
	Clearwater River	224	3,946	6.6
	Other		504	0.8
	Total		59,526	100
2002	Papoose Creek	224.120.037.105	750	1.2
	Newsome Creek	224.120.084	1,002	1.6
	Meadow Creek, Selway River	224.120.037.031	1,773	2.9
	Kooskia NFH	224.120.004.001	1,504	2.4
	Lolo Creek	224.087	1,014	1.6
	Dworshak NFH (NF Clearwater)	224.065	54,726	88.7
	Other		901	1.5
	Total		61,670	99.9
2003	Papoose Creek	224.120.037.105	799	1.3
	Newsome Creek	224.120.084	1,069	1.7
	Meadow Creek, Selway River	224.120.037.031	1,321	2.2
	Kooskia NFH	224.120.004.001	751	1.2
	Clear Creek	224.120.004	753	1.2
	Lolo Creek	224.087	1,026	1.7
	Dworshak NFH (NF Clearwater)	224.065	51,787	84.5
	Dworshak NFH	224.065	2,918	4.8
	Other		893	1.5
	Total		61,317	100.1

Table C.2: Release sites of the spring Chinook salmon release groups from the Snake River, excluding the Clearwater River (release area SNK). River kilometer (RKM) is measured from the confluence of the Snake River with the Columbia River (i.e., RKM 522 from the mouth of the Columbia River). Release sites are ordered by total RKM.

Release Year	**Release Site**	**RKM**	**Number Released**	**Percentage**
1996	Rapid River Hatchery	303.140.007.006	19,169	59.9
	Lookingglass Hatchery	271.137.003	6,758	21.1
	Imnaha River Weir	308.074	4,715	14.7
	Salmon River	303	1,257	3.9
	Other		76	0.2
	Total		31,975	99.8
1997	Pahsimeroi Pond	303.489.011	990	1.0
	Rapid River Hatchery	303.140.007.006	40,959	41.9
	Lookingglass Hatchery	271.137.003	40,404	41.4
	Imnaha River Weir	308.074	13,378	13.7
	Other		1,964	2.1
	Total		97,695	100.1
1998	Rapid River Hatchery	303.140.007.006	48,339	42.5
	Lookingglass Hatchery	271.137.003	44,788	39.4
	Imnaha River Weir	308.074	19,827	17.4
	Other		849	0.7
	Total		113,803	100
1999	Sawtooth Trap	303.617	2,966	2.3
	Rapid River Hatchery	303.140.007.006	49,288	38.8
	Lostine River	271.131.042	4,959	3.9
	Lookingglass Hatchery	271.137.003	44,554	35.1
	Imnaha River Weir	308.074	23,426	18.5
	Grande Ronde River	271	1,772	1.4
	Total		126,965	100
2000	Sawtooth Trap	303.617	1,004	1.2
	Grande Ronde River Pond	271.320	985	1.2
	Catherine Creek Pond	271.232.048	3,980	4.7

Table C.2 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2000	Rapid River Hatchery	303.140.007.006	47,748	56.5
	Lostine River Pond	271.131.042.021	7,922	9.4
	Imnaha River Weir	308.074	20,819	24.7
	Grande Ronde River	271	1,397	1.7
	Other		599	0.7
	Total		84,454	100.1
2001	Catherine Creek Pond	271.232.048	20,915	19.1
	Rapid River Hatchery	303.140.007.006	55,091	50.4
	Lostine River Pond	271.131.042.021	7,886	7.2
	Imnaha River Weir	308.074	20,922	19.1
	Grande Ronde River	271	1,628	1.5
	Other		2,824	2.6
	Total		109,266	99.9
2002	Catherine Creek Pond	271.232.048	20,796	8.4
	Rapid River Hatchery	303.140.007.006	183,923	74.6
	Lostine River Pond	271.131.042.021	16,001	6.5
	Imnaha River Weir	308.074	20,920	8.5
	Other		4,880	2.0
	Total		246,520	100
2003	Grande Ronde River Pond	271.320	2,480	1.0
	Catherine Creek Pond	271.232.048	20,628	8.4
	Rapid River Hatchery	303.140.007.006	184,473	74.7
	Lostine River Pond	271.131.042.021	15,901	6.4
	Imnaha River Weir	308.074	20,904	8.5
	Other		2,441	1.0
	Total		246,827	100

Table C.3: Release sites of the spring Chinook salmon release groups from the Snake River Basin, including the Clearwater River (release area SNB). River kilometer (RKM) is measured from the confluence of the Snake River with the Columbia River (i.e., RKM 522 from the mouth of the Columbia River). Release sites are ordered by total RKM.

Release Year	Release Site	RKM	Number Released	Percentage
1996	Powell Rearing Pond	224.120.037.113	11,402	16.7
	Red River Rearing Pond	224.120.101.027	1,212	1.8
	Rapid River Hatchery	303.140.007.006	19,169	28.0
	Crooked River Pond	224.120.094.015	2,095	3.1
	Lookingglass Hatchery	271.137.003	6,758	9.9
	Imnaha River Weir	308.074	4,715	6.9
	Clear Creek	224.120.004	16,464	24.1
	Dworshak NFH (NF Clearwater)	224.065	4,067	5.9
	North Fork Clearwater River	224.065	1,002	1.5
	Salmon River	303	1,257	1.8
	Other		233	0.3
	Total		68,374	100
1997	Rapid River Hatchery	303.140.007.006	40,959	34.6
	Lookingglass Hatchery	271.137.003	40,404	34.2
	Imnaha River Weir	308.074	13,378	11.3
	Selway River	224.120.037	1,427	1.2
	Kooskia NFH	224.120.004.001	4,075	3.4
	Dworshak NFH (NF Clearwater)	224.065	14,080	11.9
	Other		3,954	3.2
	Total		118,277	99.8
1998	Powell Rearing Pond	224.120.037.113	1,675	1.0
	Rapid River Hatchery	303.140.007.006	48,339	29.1
	Lookingglass Hatchery	271.137.003	44,788	27.0
	Imnaha River Weir	308.074	19,827	11.9
	Dworshak NFH (NF Clearwater)	224.065	47,704	28.7
	Other		3,655	2.2
	Total		165,988	99.9
1999	Sawtooth Trap	303.617	2,966	1.6

Table C.3 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1999	Rapid River Hatchery	303.140.007.006	49,288	27.1
	Lookingglass Hatchery	271.137.003	44,554	24.5
	Imnaha River Weir	308.074	23,426	12.9
	Lostine River	271.131.042	4,959	2.7
	Dworshak NFH (NF Clearwater)	224.065	47,845	26.3
	Grande Ronde River	271	1,772	1.0
	Other		7,236	3.9
	Total		182,046	100
2000	Catherine Creek Pond	271.232.048	3,980	3.0
	Rapid River Hatchery	303.140.007.006	47,748	35.4
	Lostine River Pond	271.131.042.021	7,922	5.9
	Imnaha River Weir	308.074	20,819	15.4
	Dworshak NFH (NF Clearwater)	224.065	47,745	35.4
	Grande Ronde River	271	1,397	1.0
	Other		5,209	3.7
	Total		134,820	99.8
2001	Catherine Creek Pond	271.232.048	20,915	12.4
	Rapid River Hatchery	303.140.007.006	55,091	32.6
	Lostine River Pond	271.131.042.021	7,886	4.7
	Imnaha River Weir	308.074	20,922	12.4
	Dworshak NFH (MS Clearwater)	224.065	51,196	30.3
	Grande Ronde River	271	1,628	1.0
	Clearwater River	224	3,946	2.3
	Other		7,208	4.3
	Total		168,792	100
2002	Catherine Creek Pond	271.232.048	20,796	6.7
	Rapid River Hatchery	303.140.007.006	183,923	59.7
	Lostine River Pond	271.131.042.021	16,001	5.2
	Imnaha River Weir	308.074	20,920	6.8
	Dworshak NFH (NF Clearwater)	224.065	54,726	17.8
	Other		11,824	3.8

Table C.3 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2002	Total		308,190	100
2003	Catherine Creek Pond	271.232.048	20,628	6.7
	Rapid River Hatchery	303.140.007.006	184,473	59.9
	Lostine River Pond	271.131.042.021	15,901	5.2
	Imnaha River Weir	308.074	20,904	6.8
	Dworshak NFH (NF Clearwater)	224.065	51,787	16.8
	Other		14,451	4.7
	Total		308,144	100.1

Table C.4: Release sites of the summer Chinook salmon release groups. River kilometer (RKM) is measured from the confluence of the Snake River with the Columbia River (i.e., RKM 522 from the mouth of the Columbia River). Release sites are ordered by total RKM.

Release Year	Release Site	RKM	Number Released	Percentage
1996	Knox Bridge	303.215.112	29,595	97.7
	Imnaha Trap	308.007	698	2.3
	Total		30,293	100
1997	Pahsimeroi Pond	303.489.011	31,442	36.9
	Knox Bridge	303.215.112	52,655	61.9
	Imnaha Trap	308.007	999	1.2
	Total		85,096	100
1998	Pahsimeroi Pond	303.489.011	993	2.0
	Knox Bridge	303.215.112	47,343	93.9
	Imnaha Trap	308.007	2,000	4.0
	Other		72	0.2
	Total		50,408	100.1
1999	Pahsimeroi Pond	303.489.011	500	1.0
	Knox Bridge	303.215.112	48,577	94.7

Table C.4 (continued)

Release Year	**Release Site**	**RKM**	**Number Released**	**Percentage**
1999	Imnaha Trap	308.007	1,453	2.8
	Other		787	1.5
	Total		51,317	100
2000	Knox Bridge	303.215.112	48,305	80.9
	Johnson Creek	303.215.060.024	8,045	13.5
	Imnaha Trap	308.007	2,421	4.1
	Other		969	1.6
	Total		59,740	100.1
2001	Pahsimeroi Pond	303.489.011	1,000	1.7
	Knox Bridge	303.215.112	55,727	93.3
	Imnaha Trap	308.007	3,008	5.0
	Other		4	0.0
	Total		59,739	100
2002	Pahsimeroi Pond	303.489.011	992	1.4
	Knox Bridge	303.215.112	55,432	79.8
	Johnson Creek	303.215.060.024	9,987	14.4
	Imnaha Trap	308.007	2,962	4.3
	Other		79	0.1
	Total		69,452	100
2003	Pahsimeroi Pond	303.489.011	982	1.1
	Knox Bridge	303.215.112	74,314	84.7
	Johnson Creek	303.215.060.024	12,132	13.8
	Other		323	0.4
	Total		87,751	100

Table C.5: Release sites of the steelhead release groups. River kilometer (RKM) is measured from the confluence of the Snake River with the Columbia River (i.e., RKM 522 from the mouth of the Columbia River). Release sites are ordered by total RKM.

Release Year	**Release Site**	**RKM**	**Number Released**	**Percentage**
1996	Sawtooth Hatchery	303.617	1,799	6.3
	Sawtooth Trap	303.617	903	3.1
	East Fork Salmon River Weir	303.552.030	300	1.0
	Pahsimeroi River Trap	303.489.002	1,697	5.9
	Lemhi River	303.416	299	1.0
	North Fork Salmon River	303.381	300	1.0
	Herd Creek	303.301	300	1.0
	Hazard Creek	303.140.031	304	1.1
	Red River	224.120.101	3,999	13.9
	Crooked River Trap	224.120.094.001	310	1.1
	Crooked River	224.120.094	3,005	10.5
	Big Canyon Facility	271.131.018.001	995	3.5
	Salmon Trap	303.103	1,410	4.9
	Hells Canyon Dam	522.397	300	1.0
	Little Sheep Facility	308.032.005.008	1,518	5.3
	Clear Creek	224.120.004	920	3.2
	South Fork Clearwater River	224.120	898	3.1
	Imnaha Trap	308.007	1,346	4.7
	Salmon River	303	1,505	5.2
	Dworshak NFH	224.065	4,425	15.4
	Grande Ronde River	271	287	1.0
	Snake Trap	225	1,453	5.1
	Clearwater River	224	336	1.2
	Other		81	0.3
	Total		28,690	99.8
1997	Sawtooth Hatchery	303.617	2,595	7.6
	Pahsimeroi Weir	303.489.002	798	2.4
	Hazard Creek	303.140.031	899	2.6
	Wallowa Hatchery	271.131.063.001	1,650	4.9
	Crooked River Pond	224.120.094.015	2,394	7.1
	Red River	224.120.101	1,000	2.9

Table C.5 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1997	Big Canyon Facility	271.131.018.001	2,210	6.5
	Salmon Trap	303.103	1,252	3.7
	Little Sheep Facility	308.032.005.008	812	2.4
	Clear Creek	224.120.004	991	2.9
	South Fork Clearwater River	224.120	900	2.7
	Imnaha Trap	308.007	6,118	18.0
	Salmon River	303	1,500	4.4
	Dworshak NFH	224.065	4,874	14.4
	Grande Ronde River	271	2,356	6.9
	Snake Trap	225	1,459	4.3
	Other		2,119	6.3
	Total		33,927	100
1998	Sawtooth Hatchery	303.617	1,200	4.0
	East Fork Salmon River Weir	303.552.030	300	1.0
	Squaw Creek Acclimation Pond	303.564.001	899	3.0
	Pahsimeroi River Trap	303.489.002	300	1.0
	Herd Creek	303.301	1,205	4.0
	Hazard Creek	303.140.031	900	3.0
	Wallowa Hatchery	271.131.063.001	1,108	3.6
	Red River	224.120.101	4,116	13.6
	Big Canyon Facility	271.131.018.001	1,202	4.0
	Twentymile Creek	224.120.069	326	1.1
	Salmon Trap	303.103	1,117	3.7
	Hells Canyon Dam	522.397	300	1.0
	Little Sheep Facility	308.032.005.008	862	2.8
	Clear Creek	224.120.004	303	1.0
	South Fork Clearwater River	224.120	300	1.0
	Imnaha Trap	308.007	3,859	12.7
	Salmon River	303	1,499	4.9
	Dworshak NFH	224.065	3,497	11.5
	Grande Ronde River	271	2,730	9.0
	Snake Trap	225	4,274	14.1
	Other		78	0.3

Table C.5 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1998	Total		30,375	100.3
1999	Sawtooth Hatchery	303.617	2,399	6.2
	Squaw Creek Acclimation Pond	303.564.001	1,496	3.9
	Wallowa Hatchery	271.131.063.001	1,354	3.5
	Red River	224.120.101	5,000	12.9
	Little Salmon River	303.140	599	1.5
	Big Canyon Facility	271.131.018.001	2,330	6.0
	Salmon Trap	303.103	2,266	5.8
	Little Sheep Facility	308.032.005.008	761	2.0
	Clear Creek	224.120.004	1,498	3.9
	South Fork Clearwater River	224.120	1,198	3.1
	Imnaha Trap	308.007	6,387	16.5
	Salmon River	303	924	2.4
	Dworshak NFH (MS Clearwater)	224.065	2,108	5.4
	Grande Ronde River	271	3,116	8.0
	Snake Trap	225	3,990	10.3
	Clearwater River	224	1,921	5.0
	Other		1,427	3.7
	Total		38,774	100.1
2000	Sawtooth Hatchery	303.617	2,408	6.6
	Squaw Creek Acclimation Pond	303.564.001	1,791	4.9
	Wallowa Hatchery	271.131.063.001	1,195	3.3
	Little Salmon River	303.140	599	1.6
	Big Canyon Facility	271.131.018.001	3,509	9.6
	Salmon Trap	303.103	2,126	5.8
	Little Sheep Facility	308.032.005.008	756	2.1
	Clear Creek	224.120.004	1,200	3.3
	South Fork Clearwater River	224.120	1,200	3.3
	Cottonwood Acclimation Pond	271.046	354	1.0
	Imnaha Trap	308.007	5,742	15.8
	Salmon River	303	597	1.6
	Dworshak NFH (MS Clearwater)	224.065	4,208	11.6

Table C.5 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2000	North Fork Clearwater River	224.065	782	2.1
	Grande Ronde River	271	2,951	8.1
	Snake Trap	225	3,698	10.2
	Clearwater River	224	699	1.9
	Other		2,574	6.9
	Total		36,389	99.7
2001	Sawtooth Hatchery	303.617	500	1.6
	Yankee Fork (Salmon River)	303.591	597	1.9
	Squaw Creek Acclimation Pond	303.564.001	900	2.9
	Squaw Creek (Salmon River)	303.564	600	1.9
	Pahsimeroi River Trap	303.489.002	302	1.0
	Lemhi River	303.416	300	1.0
	Red River Rearing Pond	224.120.101.027	299	1.0
	Wallowa Hatchery	271.131.063.001	890	2.9
	Crooked River Pond	224.120.094.015	598	1.9
	American River	224.120.101	295	1.0
	Little Salmon River	303.140	900	2.9
	Newsome Creek	224.120.084	300	1.0
	Big Canyon Facility	271.131.018.001	2,068	6.7
	Salmon Trap	303.103	3,084	10.0
	Hells Canyon Dam	522.397	300	1.0
	Little Sheep Facility	308.032.005.008	747	2.4
	Clear Creek	224.120.004	903	2.9
	South Fork Clearwater River	224.120	1,199	3.9
	Cottonwood Acclimation Pond	271.046	346	1.1
	Imnaha Trap	308.007	3,463	11.2
	Lolo Creek	224.087	318	1.0
	Salmon River	303	1,300	4.2
	Dworshak NFH (MS Clearwater)	224.065	4,205	13.6
	North Fork Clearwater River	224.065	663	2.1
	Grande Ronde River	271	2,216	7.2
	Snake Trap	225	2,940	9.5
	Clearwater River	224	665	2.1

Table C.5 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2001	Other		86	0.3
	Total		30,984	100.2
2002	Sawtooth Hatchery	303.617	599	1.9
	Squaw Creek Acclimation Pond	303.564.001	1,200	3.9
	Squaw Creek (Salmon River)	303.564	600	1.9
	Pahsimeroi River Trap	303.489.002	300	1.0
	Lemhi River	303.416	594	1.9
	Red River Rearing Pond	224.120.101.027	298	1.0
	Wallowa Hatchery	271.131.063.001	737	2.4
	Crooked River Pond	224.120.094.015	601	1.9
	Little Salmon River	303.140	599	1.9
	Big Canyon Facility	271.131.018.001	3,852	12.4
	Salmon Trap	303.103	2,060	6.6
	Hells Canyon Dam	522.397	298	1.0
	Little Sheep Facility	308.032.005.008	751	2.4
	Clear Creek	224.120.004	900	2.9
	South Fork Clearwater River	224.120	1,202	3.9
	Imnaha Trap	308.007	2,153	6.9
	Salmon River	303	2,099	6.8
	Dworshak NFH (MS Clearwater)	224.065	4,213	13.6
	Grande Ronde River Trap	271.002	2,418	7.8
	Snake Trap	225	5,031	16.2
	Other		498	1.6
	Total		31,003	99.9
2003	Yankee Fork (Salmon River)	303.591	596	1.9
	Squaw Creek Acclimation Pond	303.564.001	599	1.9
	Lemhi River	303.416	597	1.9
	Wallowa Hatchery	271.131.063.001	493	1.5
	Crooked River Pond	224.120.094.015	648	2.0
	American River	224.120.101	526	1.6
	Red River	224.120.101	535	1.7
	Little Salmon River	303.140	1,175	3.7

Table C.5 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2003	Crooked River	224.120.094	841	2.6
	Newsome Creek	224.120.084	519	1.6
	Big Canyon Facility	271.131.018.001	3,967	12.4
	Salmon Trap	303.103	2,444	7.6
	Mill Creek, SF Clearwater River	224.120.052	526	1.6
	Little Sheep Facility	308.032.005.008	772	2.4
	South Fork Clearwater River	224.120	883	2.8
	Imnaha Trap	308.007	5,227	16.3
	Lolo Creek	224.087	535	1.7
	Salmon River	319 - 489	900	2.8
	Dworshak NFH (MS Clearwater)	224.065	1,500	4.7
	Grande Ronde River Trap	271.002	2,210	6.9
	Snake Trap	225	4,177	13.0
	Other		2,338	7.1
	Total		32,008	99.7

C.2 Detection Sites

Table C.6 identifies the detection sites used for each release group.

Table C.6: Detection sites used for each release group by year of release and species. CLR = Clearwater River Basin; SNK = Snake River (excluding Clearwater); SNB = Snake River Basin (including Clearwater).

Release		Release	Juvenile Sites						Adult Sites			
Year	**Species**	**Area**	**LGR**	**LGS**	**LMN**	**MCN**	**JD**	**BON**	**BON**	**MCN**	**IH**	**LGR**
1996	Spring Chinook	CLR	X	X	X	X	-	-	-	-	-	X
1997			X	X	X	X	-	-	-	-	-	X
1998			X	X	X	X	X	X	-	-	-	X
1999			X	X	X	X	X	X	X	-	-	X
2000			X	X	X	X	X	X	X	-	-	X
2001			X	X	X	X	X	X	X	-	-	X
2002			X	X	X	X	X	X	X	X	X	X
2003			X	X	X	X	X	X	X	X	X	X
1996	Spring Chinook	SNK	X	X	X	X	-	-	-	-	-	X
1997			X	X	X	X	-	X	-	-	-	X
1998			X	X	X	X	X	X	-	-	-	X
1999			X	X	X	X	X	X	X	-	-	X
2000			X	X	X	X	X	X	X	-	-	X
2001			X	X	X	X	X	X	X	-	-	X
2002			X	X	X	X	X	X	X	X	X	X
2003			X	X	X	X	X	X	X	X	X	X
1996	Spring Chinook	SNB	X	X	X	X	-	-	-	-	-	X
1997			X	X	X	X	-	-	-	-	-	X
1998			X	X	X	X	X	X	-	-	-	X
1999			X	X	X	X	X	X	X	-	-	X

Table C.6 (continued)

Release		Release	Juvenile Sites						Adult Sites			
Year	**Species**	**Area**	**LGR**	**LGS**	**LMN**	**MCN**	**JD**	**BON**	**BON**	**MCN**	**IH**	**LGR**
2000	Spring Chinook	SNB	X	X	X	X	X	X	X	-	-	X
2001			X	X	X	X	X	X	X	-	-	X
2002			X	X	X	X	X	X	X	X	X	X
2003			X	X	X	X	X	X	X	X	X	X
1996[a]	Summer Chinook	SNB	X	X	X	X	-	-	-	-	-	X
1997			X	X	X	X	-	X	-	-	-	X
1998			X	X	X	X	X	-	-	-	-	X
1999			X	X	X	X	X	X	X	-	-	X
2000			X	X	X	X	X	X	X	-	-	X
2001[a]			X	X	X	X	X	X	X	-	-	X
2002			X	X	X	X	X	X	X	X	X	X
2003			X	X	X	X	X	X	X	X	X	X
1996	Steelhead	SNB	X	X	X	X	-	-	-	-	-	X
1997			X	X	X	X	-	X	-	-	-	X
1998[a]			X	X	X	X	X	X	-	-	-	X
1999			X	X	X	X	X	X	X	-	-	X
2000			X	X	X	X	X	X	X	-	-	X
2001[b]			X	X	X	X	X	X	X	-	-	X
2002			X	X	X	X	X	X	X	X	X	X
2003			X	X	X	X	X	X	X	X	X	X

[a]Heuristic performance measures were estimated using juvenile inriver survival estimate to LGR.

[b]There were too few adult detections from 2001 steelhead to use the ROSTER model. Instead, juvenile detection sites LGR and LGS were used, and all later detections were pooled. Detection histories were analyzed using the CJS model (with removals), and heuristic performance measures were estimated.

C.3 PitPro Error Summaries

PitPro performs error checking while converting the raw release and observation data to detection histories. Tags flagged as errors are removed from the data set. PitPro searches for 14 types of errors, but only 5 error types were found in the data analyzed in this report. Tables C.8 to C.12 summarize the errors found for these data, using error codes defined in Table C.7. Some tags have multiple errors.

Table C.7: Descriptions and codes for data errors detected by PitPro for the spring and summer Chinook salmon and steelhead releases analyzed in this report.

Error Code	**Error Description**
A	Observation on known juvenile detector outside of migration year.
B	Observations are out of sequence.
C	Fish observed before release date.
D	Fish removed before first capture history site.
E	Fish observed in year following migration year before cutoff.

Table C.8: PitPro error summary for the spring Chinook salmon release groups from the Clearwater Basin (release area CLR). Error codes are defined in Table C.7. Final N is the size of the release group after removing tags with errors.

Release	**Error Type**					**Total**	**Final**
Year	A	B	C	D	E	**Errors**	N
1996	8	4	9	146	0	167	36,232
1997	0	2	1	146	0	149	20,433
1998	0	2	0	4	0	6	52,179
1999	0	14	0	6	0	20	55,061
2000	1	0	3	7	0	11	50,355
2001	33	1	1	1	0	36	59,490
2002	0	17	0	3	0	20	61,650
2003	1	1	0	4	0	6	61,311

Table C.9: PitPro error summary for the spring Chinook salmon release groups from the Snake River, excluding the Clearwater River (release area SNK). Error codes are defined in Table C.7. Final N is the size of the release group after removing tags with errors.

Release	**Error Type**					**Total**	**Final**
Year	A	B	C	D	E	**Errors**	N
1996	10	2	3	699	0	711	31,264
1997	2	6	25	3,064	0	3,071	94,624
1998	0	2	212	4,139	0	4,289	109,514
1999	0	30	25	1,907	0	1,941	125,024
2000	5	1	1	2,970	0	2,976	81,478
2001	2	8	4	6,488	0	6,501	102,765
2002	18	114	49	4,729	0	4,868	241,652
2003	0	57	6	3,230	0	3,288	243,539

Table C.10: PitPro error summary for the spring Chinook salmon release groups from the Snake River Basin, including the Clearwater River (release area SNB). Error codes are defined in Table C.7. Final N is the size of the release group after removing tags with errors.

Release	**Error Type**					**Total**	**Final**
Year	A	B	C	D	E	**Errors**	N
1996	18	6	12	845	0	878	67,496
1997	2	8	26	3,210	0	3,220	115,057
1998	0	4	212	4,143	0	4,295	161,693
1999	0	44	25	1,913	0	1,961	180,085
2000	6	1	4	2,977	0	2,987	131,832
2001	35	9	5	6,489	0	6,537	162,255
2002	18	131	49	4,732	0	4,888	303,302
2003	1	58	6	3,234	0	3,294	304,850

Table C.11: PitPro error summary for the summer Chinook salmon release groups. Error codes are defined in Table C.7. Final N is the size of the release group after removing tags with errors.

Release	**Error Type**					**Total**	**Final**
Year	A	B	C	D	E	**Errors**	N
1996	8	3	8	94	0	112	28,062
1997	0	14	1	62	0	76	85,020
1998	0	1	0	146	0	147	50,261

Table C.11 (continued)

Release Year	**Error Type** A	B	C	D	E	**Total Errors**	**Final** N
1999	0	4	0	141	0	145	51,172
2000	0	0	0	1,260	0	1,260	58,479
2001	1	5	1	144	0	151	59,588
2002	1	21	0	946	0	968	68,484
2003	0	4	0	93	0	97	87,654

Table C.12: PitPro error summary for the steelhead release groups. Error codes are defined in Table C.7. Final N is the size of the release group after removing tags with errors.

Release Year	**Error Type** A	B	C	D	E	**Total Errors**	**Final** N
1996	27	2	2	486	24	516	28,174
1997	17	1	2	154	17	173	33,754
1998	20	0	2	38	22	63	30,312
1999	0	0	19	60	0	77	38,697
2000	79	1	3	105	75	192	36,197
2001	107	0	8	84	102	198	30,786
2002	33	1	1	65	33	100	30,903
2003	14	1	19	111	13	145	31,863

Appendix D

Statistical Likelihood Model

The statistical release-recapture model used to analyze the data is a multinomial likelihood model that estimates survival, detection, censoring, and transportation parameters (Table D.1). These parameters are used to define the performance measures (Appendix E). The likelihood (Eqs. (D.9) and (D.10)) is most concisely expressed using summary statistics based on the detection histories (Table D.2).

For the purposes of this Appendix, v is the number of juvenile detection sites, u is the number of adult detection sites, and w is the number of returning adult age classes (including the age-1-ocean age class). Also, i is the detection site index, and j is the adult age class index, where $j = 1$ corresponds to the age-1-ocean age class.

Table D.1: Estimable parameters, where v is the number of juvenile detection sites, u is the number of adult detection sites, and w is the number of returning adult age classes.

Parameter	**Definition**
S_1	Probability of juvenile survival from release point to first detection site;
S_i	Conditional probability of juvenile inriver (nontransport) survival from detection site $i-1$ to detection site i; $i = 2, \ldots, v$;
$S_{v+1,jC}$	Conditional joint probability of surviving from juvenile site v to adult site $v+1$ and maturing after j years in the ocean, for nontransported (i.e., control) fish; $j = 1, \ldots, w$;
S_{ijC}	Conditional probability of adult survival from site $i-1$ to site i for non-transported age-j-ocean adults; $i = v+2, \ldots, v+u-1$; $j = 1, \ldots, w$;
S_{ijT_k}	Conditional probability of adult survival from site $i-1$ to site i for site-k transport, age-j-ocean adults; $i = v+2, \ldots, v+u-1$; $j = 1, \ldots, w$; $k = 1, \ldots, v$;

Table D.1 (continued)

Parameter	Definition
p_i	Conditional probability of juvenile detection at site i, given survival to site i and inriver at i; $i = 1, \ldots, v$; $q_i = 1 - p_i$;
p_{ijC}	Conditional probability of adult detection at site i, given survival to i, for non-transported age-j-ocean adults; $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$; $q_{ijC} = 1 - p_{ijC}$;
p_{ijT_k}	Conditional probability of adult detection at site i, given survival to i, for site-k transport, age-j-ocean adults; $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$; $k = 1, \ldots, v$; $q_{ijT_k} = 1 - p_{ijT_k}$;
λ_{jC}	Conditional probability of nontransported, age-j-ocean adults surviving to and being detected at site $v+u$, given survival to site $v+u-1$; $j = 1, \ldots, w$;
λ_{jT_k}	Conditional probability of site-k transport, age-j-ocean adults surviving to and being detected at adult $v+u$, given survival to site $v+u-1$; $j = 1, \ldots, w$; $k = 1, \ldots, v$;
c_i	Conditional probability of juvenile censoring (known removal) at site i, given detection at i; $i = 1, \ldots, v$;
c_{ij}	Conditional probability of adult censoring (known removal) at adult site i for age-j-ocean adults, given detection at i; $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$;
t_i	Conditional probability of being transported at juvenile site i, given detection at i and no censoring; $i = 1, \ldots, v$;
R_{ij}	Site $v+1$-specific Transport-Inriver ratio (T/I) for fish transported from juvenile site i and detected as an age-j-ocean adult; $i = 1, \ldots, v$; $j = 1, \ldots, w$;
χ_{iC}	Conditional probability of not being detected after juvenile site i, given passing site i inriver (nontransported); $i = 1, \ldots, v$;
χ_{ijC}	Conditional probability of not being detected after adult site i, given passing site i as a nontransported age-j-ocean adult; $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$;
χ_{iT}	Conditional probability of not being detected after juvenile site i, given being transported from site i; $i = 1, \ldots, v$;
χ_{ijT_k}	Conditional probability of not being detected after adult site i, given passing site i as a site-k transport, age-j-ocean adult; $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$; $k = 1, \ldots, v$.

The χ_{iC}, χijC, χ_{iT}, and χijT_k parameters can be expressed in terms of other model parameters as follows:

$$\chi_{iC} = \begin{cases} 1 - S_{i+1} + S_{i+1} q_{i+1} \chi_{i+1,C} & \text{for } i = 0, \ldots, v-1; \\ 1 - \sum_{j=1}^{w} S_{v+1,jC} + \sum_{j=1}^{w} S_{v+1,jC} q_{v+1,jC} \chi_{v+1,jC} & \text{for } i = v; \end{cases} \tag{D.1}$$

$$\chi_{ijC} = \begin{cases} 1 - S_{i+1,jC} + S_{i+1,jC} q_{i+1,jC} \chi_{i+1,jC} & \text{for } i = v+1, \ldots, v+u-2; \\ 1 - \lambda_{jC} & \text{for } i = v+u-1; \end{cases} \tag{D.2}$$

$$\begin{aligned} \chi_{iT} = 1 - S_{i+1} \cdots S_v \sum_{j=1}^{w} S_{v+1,jC} R_{ij} \\ + S_{i+1} \cdots S_v \sum_{j=1}^{w} S_{v+1,jC} R_{ij} q_{v+1,jT_i} \chi_{v+1,jT_i} \quad \text{for } i = 1, \ldots, v; \end{aligned} \tag{D.3}$$

$$\chi_{ijT_k} = \begin{cases} 1 - S_{i+1,jT_k} + S_{i+1,jT_k} q_{i+1,jT_k} \chi_{i+1,jT_k} & \text{for } i = v+1, \ldots, v+u-2; \quad k = 1, \ldots, v; \\ 1 - \lambda_{jT_k} & \text{for } i = v+u-1; \quad k = 1, \ldots, v. \end{cases} \tag{D.4}$$

Table D.2: Summary statistics for generalized model, where v is the number of juvenile detection sites, u is the number of adult detection sites, and w is the number of returning adult age classes.

Statistic	**Definition**
a_i	Number detected at juvenile site i (includes those transported from i); $i = 1, \ldots, v$;
a_{ijC}	Number of nontransported fish detected at adult site i as age-j-ocean adult; $i = v+1, \ldots, v+u$; $j = 1, \ldots, w$;
a_{ijT_k}	Number of site-k transport fish detected at adult site i as age-j-ocean adult; $i = v+1, \ldots, v+u$; $j = 1, \ldots, w$; $k = 1, \ldots, v$;
b_i	Number detected at juvenile site i, re-released to the river, and detected at later site (juvenile or adult); $i = 0, \ldots, v$ ($i = 0$ represents initial release);
b_{iT}	Number detected and transported from juvenile site i and detected later at adult site; $i = 1, \ldots, v$;
b_{ijC}	Number of nontransported fish detected and released to the river at site i, and *next* detected at an adult site as an age-j-ocean adult; $i = 0, \ldots, v+u-1$; $j = 1, \ldots, w$;

Table D.2 (continued)

Statistic	Definition
b_{ijT}	Number transported from juvenile site i and detected again at an adult site as age-j-ocean adult; $i = 1, \ldots, v$; $j = 1, \ldots, w$;
b_{ijT_k}	Number of site-k transport fish detected and released to the river at adult site i as age-j-ocean adult, and detected at later adult site (as age-j-ocean adult); $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$; $k = 1, \ldots, v$;
d_i	Number censored at juvenile site i; $i = 1, \ldots, v$;
d_{ijC}	Number of nontransported fish censored at adult site i as age-j-ocean adult; $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$;
d_{ijT_k}	Number of site-k transport fish censored at adult site i as age-j-ocean adult; $i = v+1, \ldots, v+u-1$; $j = 1, \ldots, w$; $k = 1, \ldots, v$;
h_i	Number transported from juvenile site i; $i = 1, \ldots, v$;
g_i	Number of fish *not* transported from any site $k \leq i$ that are detected *after* juvenile site i; $i = 0, \ldots, v-1$;
g_{ijC}	Number of nontransported fish detected *after* site i as age-j-ocean adult; $i = v, \ldots, v+u-1$; $j = 1, \ldots, w$;
g_{ijT_k}	Number of site-k transport fish detected *after* site i as age-j-ocean adult; $i = v, \ldots, v+u-1$; $j = 1, \ldots, w$; $k = 1, \ldots, v$;
g_{iT_k}	Number of site-k transport fish detected *after* juvenile site i; $=b_{kT}$; $i = k, \ldots, v$.

The g_i, g_{ijC}, g_{ijT_k}, and g_{iT_k} statistics can be expressed in terms of other summary statistics as follows:

$$g_i = \begin{cases} b_0 & \text{for } i = 0; \\ g_{i-1} + b_i - a_i & \text{for } i = 1, \ldots, v-1; \end{cases} \tag{D.5}$$

$$g_{iT_k} = b_{kT} \quad \text{for } i = k, \ldots, v; \tag{D.6}$$

$$g_{ijC} = \begin{cases} \sum_{s=0}^{v} b_{sjC} & \text{for } i = v; \quad j = 1, \ldots, w; \\ g_{i-1,jC} + b_{ijC} - a_{ijC} & \text{for } i = v+1, \ldots, v+u-1; \quad j = 1, \ldots, w; \end{cases} \tag{D.7}$$

$$
g_{ijT_k} = \begin{cases} b_{kjT} & \text{for } i = v; \\ g_{i-1,jT_k} + b_{ijT_k} - a_{ijT_k} & \text{for } i = v+1, \ldots, v+u-1; \quad j = 1, \ldots, w; \quad k = 1, \ldots, v. \end{cases} \tag{D.8}
$$

The likelihood can be expressed as follows:

$$
\begin{aligned}
L \propto\ & \chi_0^{N-b_0} \prod_{i=1}^{v} \left\{ S_i^{g_{i-1}+\sum_{k=1}^{i-1} b_{kT}} p_i^{a_i} q_i^{g_{i-1}-a_i} c_i^{d_i} (1-c_i)^{a_i-d_i} t_i^{h_i} (1-t_i)^{a_i-d_i-h_i} \chi_i^{a_i-d_i-h_i-b_i} \chi_{iT}^{h_i-b_{iT}} \right\} \\
& \times \prod_{j=1}^{w} \left\{ \lambda_{jC}^{g_{v+u-1,jC}} S_{v+1,jC}^{g_{vjC}+\sum_{k=1}^{v} b_{kjT}} \prod_{k=1}^{v} \left[R_{kj}^{b_{kjT}} \lambda_{jT_k}^{g_{v+u-1,jT_k}} \right] \prod_{i=v+2}^{v+u-1} \left[S_{ijC}^{g_{i-1,jC}} \prod_{k=1}^{v} (S_{ijT_k}^{g_{i-1,jT_k}}) \right] \right. \\
& \times \prod_{i=v+1}^{v+u-1} \left[p_{ijC}^{a_{ijC}} q_{ijC}^{g_{i-1,jC}-a_{ijC}} c_{ij}^{d_{ijC}+\sum_{k=1}^{v} d_{ijT_k}} (1-c_{ij})^{a_{ijC}-d_{ijC}+\sum_{k=1}^{v}(a_{ijT_k}-d_{ijT_k})} \chi_{ijC}^{a_{ijC}-d_{ijC}-b_{ijC}} \right. \\
& \left. \left. \times \prod_{k=1}^{v} \left(p_{ijT_k}^{a_{ijT_k}} q_{ijT_k}^{g_{i-1,jT_k}-a_{ijT_k}} \chi_{ijT_k}^{a_{ijT_k}-d_{ijT_k}-b_{ijT_k}} \right) \right] \right\}.
\end{aligned} \tag{D.9}
$$

Equivalently, the log-likelihood is:

$$
\begin{aligned}
\log L \propto\ & (N-b_0) \log \chi_0 \\
& + \sum_{i=1}^{v} \left\{ (g_{i-1} + \sum_{k=1}^{i-1} b_{kT}) \log S_i + a_i \log p_i + (g_{i-1} - a_i) \log q_i + d_i \log c_i + (a_i - d_i) \log(1-c_i) \right. \\
& \left. + h_i \log t_i + (a_i - d_i - h_i) \log(1-t_i) + (a_i - d_i - h_i - b_i) \log \chi_i + (h_i - b_{iT}) \log \chi_{iT} \right\} \\
& + \sum_{j=1}^{w} \left\{ (g_{v+u-1,jC}) \log \lambda_{jC} + (g_{vjC} + \sum_{k=1}^{v} b_{kjT}) \log S_{v+1,jC} \right. \\
& + \sum_{k=1}^{v} \left[b_{kjT} \log R_{kj} + g_{v+u-1,jT_k} \log \lambda_{jT_k} \right] + \sum_{i=v+2}^{v+u-1} \left[g_{i-1,jC} \log S_{ijC} + \sum_{k=1}^{v} \left(g_{i-1,jT_k} \log S_{ijT_k} \right) \right] \\
& + \sum_{i=v+1}^{v+u-1} \left[a_{ijC} \log p_{ijC} + (g_{i-1,jC} - a_{ijC}) \log q_{ijC} + (d_{ijC} + \sum_{k=1}^{v} d_{ijT_k}) \log c_{ij} \right. \\
& + \left(a_{ijC} - d_{ijC} + \sum_{k=1}^{v} [a_{ijT_k} - d_{ijT_k}] \right) \log(1-c_{ij}) + (a_{ijC} - d_{ijC} - b_{ijC}) \log \chi_{ijC} \\
& \left. \left. + \sum_{k=1}^{v} \left(a_{ijT_k} \log p_{ijT_k} + (g_{i-1,jT_k} - a_{ijT_k}) \log q_{ijT_k} + (a_{ijT_k} - d_{ijT_k} - b_{ijT_k}) \log \chi_{ijT_k} \right) \right] \right\}.
\end{aligned} \tag{D.10}
$$

Appendix E

Performance Measures Theory

The performance measures reported in this report are defined in this Appendix, in terms of the model parameters defined in Appendix D. Maximum likelihood estimates (MLEs) of the performance measures are found by replacing each parameter with its MLE, found by fitting the model. Variances are estimated by the Delta Method (Seber 1982, pp.7-9), as follows: Let $\Psi = f(\theta_1, \ldots, \theta_n)$ be a performance measure that is a function of model parameters $\theta_1, \ldots, \theta_n$. Then the MLE of Ψ is $\widehat{\Psi} = f\left(\widehat{\theta}_1, \ldots, \widehat{\theta}_n\right)$, where $\widehat{\theta}_i$ is the MLE of model parameter θ_i, and the variance of $\widehat{\Psi}$ is estimated by

$$\widehat{Var}\left(\widehat{\Psi}\right) = \sum_{i=1}^{n}\left(\frac{\partial\Psi}{\partial\theta_i}\right)^2 \widehat{Var}\left(\widehat{\theta}_i\right) + 2\sum_{i=k+1}^{n}\sum_{k=1}^{n}\left(\frac{\partial\Psi}{\partial\theta_i}\right)\left(\frac{\partial\Psi}{\partial\theta_k}\right)\widehat{Cov}\left(\widehat{\theta}_i, \widehat{\theta}_k\right), \tag{E.1}$$

where the partial derivatives are evaluated at the MLEs of the parameters. The estimated standard error of the estimator is the square root of the variance estimate: $\widehat{SE}\left(\widehat{\Psi}\right) = \sqrt{\widehat{Var}\left(\widehat{\Psi}\right)}$.

Each performance measure is defined below in terms of model parameters, and the partial derivatives necessary to estimate the standard error are given. For all performance measures, v is the number of juvenile detection sites, u is the number of adult detection sites, and w is the number of returning adult age classes (including jacks). Also, i is the detection site index, and j is the adult age class index ($j = 1$ represents the age-1-ocean age class). For steelhead, performance measures are estimated using all age classes, so j ranges from 1 through w, the oldest adult age class. For Chinook, performance measures are estimated using only the older adult age classes, omitting the jacks (age-1-ocean fish); thus, for Chinook, j ranges from 2 through w. Formulas show j ranging from 1 to w; it should be understood that j (and any other index of adult age) is restricted to 2 through w for Chinook. Parameters used in the performance measures are defined in Table D.1. For the following performance measures, the parameter $S_{v+u,jC}$ or S_{v+u,jT_l} should be replaced with λ_{jC} or λ_{jT_l}, respectively.

E.1 Survival

Four measures of survival are reported: juvenile inriver survival from Lower Granite Dam to Bonneville Dam (S_J), the ocean return probability from Bonneville to the first adult detection site for nontransported fish (O_{NT}), adult upriver survival for the entire release group from Bonneville to Lower Granite (S_A), and the smolt-to-adult return ratio to Lower Granite (SAR) for the entire release group.

E.1.1 Juvenile Inriver Survival

Juvenile inriver survival from Lower Granite to Bonneville is S_J. If Bonneville is the final juvenile detection site, then it is possible to estimate S_J directly from the PIT-tag data, using estimates of model parameters S_i ($i = 2, \ldots, v$). If the final juvenile detection site is upstream of Bonneville Dam, it is necessary to extrapolate the estimate based on the S_i parameters to reflect mortality between the final juvenile detection site and Bonneville. Extrapolation can be done on a per-site (detection site), per-project, or per-RKM basis. The best extrapolation method is selected on the basis of the chi-square statistic that compares observed and expected reach-specific survivals (i.e., S_i) for reaches included in the data set. Depending on the type of extrapolation, let y be the number of detection sites, hydroelectric projects, or river kilometers between Lower Granite and the final juvenile detection site, and let x be the number of detection sites, hydroelectric projects, or river kilometers between Lower Granite and Bonneville ($x = 5$ for per-site method if John Day is a detection site). Then S_J is defined as

$$S_J = \left(\prod_{i=2}^{v} S_i \right)^{\frac{x}{y}}, \tag{E.2}$$

where x and y are determined based on the type of extrapolation used in the case where Bonneville is not the final juvenile detection site. If Bonneville is the final juvenile detection site, then $x = y$ and $S_J = \prod_{i=2}^{v} S_i$. The partial derivatives necessary for estimating the standard error are

$$\frac{\partial S_J}{\partial S_i} = \frac{x S_J}{y S_i}, \qquad i = 2, \ldots, v.$$

The appropriate extrapolation method is chosen by minimizing the chi-square goodness-of-fit statistic, which can be calculated for each method. As above, let y be the number of detection sites, hydroelectric projects, or river kilometers between Lower Granite and the final detection site, depending on the extrapolation method. Then for each extrapolation method, the unit survival is

$$\widehat{S_{\text{unit}}} = \left[\prod_{i=2}^{v} \widehat{S}_i \right]^{1/y}, \tag{E.3}$$

where $\widehat{S}_i$ is the MLE of S_i found by fitting the ROSTER model. For each extrapolation method, the predicted survival parameter $\tilde{S}_i$ is defined:

$$\tilde{S}_i = \begin{cases} \widehat{S_{\text{unit}}} & \text{for per-site extrapolation method;} \\ \widehat{S_{\text{unit}}^{x_{Pi}}} & \text{for per-project extrapolation method and } x_{Pi} \text{ in Table E.1;} \\ \widehat{S_{\text{unit}}^{x_{Ki}}} & \text{for per-RKM extrapolation method and } x_{Ki} \text{ in Table E.2.} \end{cases}$$

Table E.1: Values of x_{Pi} for Goodness-of-Fit statistic for per-project extrapolation of juvenile inriver survival in the case where John Day is included among the detection sites. The index x_{Pi} is the number of hydroelectric projects between site $i-1$ and site i. Thus, if John Day is not a detection site, then Bonneville is site 5, and has value $x_{P5} = 3$.

i	**Site**	**Project Number**	x_{Pi}
1	LGR	1	–
2	LGS	2	1
3	LMO	3	1
4	MCN	5	2
5	JD	6	1
6	BON	8	2

Table E.2: Values of x_{Ki} for Goodness-of-Fit statistic for per-RKM extrapolation of juvenile inriver survival in the case where John Day is included among the detection sites. The index x_{Ki} is the number of river kilometers (RKM) between site $i-1$ and site i. Thus, if John Day is not a detection site, then Bonneville is site 5, and has value $x_{K5} = 236$.

i	**Site**	**RKM**	x_{Ki}
1	LGR	695	–
2	LGS	635	60
3	LMO	589	46
4	MCN	470	119
5	JD	347	123
6	BON	234	113

For each extrapolation method, the goodness-of-fit statistic, χ^2, is defined as

$$\chi^2 = \sum_{i=2}^{v} \frac{\left(\widehat{S}_i - \tilde{S}_i\right)^2}{\tilde{S}_i}. \tag{E.4}$$

The extrapolation method with the smallest χ^2 value is used to estimate juvenile inriver survival in the event that Bonneville is not a juvenile detection site.

E.1.2 Ocean Return Probability

The ocean return probability is the survival probability from Bonneville back to Bonneville. This measure includes ocean survival, as well as survival between the ocean and Bonneville. It is reported without the age-1-ocean ("jack") age class for Chinook and with the age-1-ocean age class for steelhead, and is reported separately for nontransported and transported fish. For Chinook, the index j used in the formulas below should range from 2 to w, the oldest age class.

Ocean Return Probability for Nontransported Fish

The ocean return probability for nontransported ("NT") fish is O_{NT}. In the case where Bonneville is the final juvenile detection site, O_{NT} is just the sum of the age-specific ocean return parameters $S_{v+1,jC}$ (Eq. (E.5)). If the final juvenile site is upriver from Bonneville, then the parameters $S_{v+1,jC}$ include juvenile survival from the last juvenile site (e.g., John Day) to Bonneville, as well as ocean survival. In these cases, the sum of the $S_{v+1,jC}$ parameters can be adjusted for this extra inriver survival using the same method used to extrapolate juvenile inriver survival: either the per-site, per-project, or per-RKM method. As with S_J, let y be the number of detection sites, hydroelectric projects, or river kilometers between Lower Granite and the final detection site, depending on the extrapolation method, and let x be the number of detection sites, hydroelectric projects, or river kilometers between Lower Granite and Bonneville ($x = 5$ for per-site method if John Day is a detection site). Then the ocean return probability is defined as

$$\begin{aligned} O_{NT} &= Pr\big[\text{Return to site } v+1 \mid \text{Migrated to BON as nontransported juvenile}\big] \\ &= \left(\prod_{i=2}^{v} S_i\right)^{1-\frac{x}{y}} \sum_{j=1}^{w} S_{v+1,jC}. \end{aligned} \tag{E.5}$$

The partial derivatives necessary for estimating the standard error are:

$$\begin{aligned} \frac{\partial O_{NT}}{\partial S_i} &= \frac{\left(1-\frac{x}{y}\right) O_{NT}}{S_i}, & i &= 2,\ldots,v \\ \frac{\partial O_{NT}}{\partial S_{v+1,jC}} &= \left(\prod_{i=2}^{v} S_i\right)^{1-\frac{x}{y}}, & j &= 1,\ldots,w. \end{aligned}$$

Ocean Return Probability for Site-i Transport Fish

The ocean return probability for fish transported from site-i is O_i. This measure uses the assumption that survival of transported fish in the barge is 0.98. Each data set for which O_i is estimated here included Bonneville as the final juvenile detection site, so it was unnecessary to adjust the ocean return parameters $S_{v+1,j}$ for extra inriver survival. For transport dam i ($i = 1, \ldots, v$):

$$\begin{aligned} O_i &= Pr\big[\text{Return to site } v+1 \mid \text{Transported at dam } i\big] \\ &= \frac{\left(\prod_{k=i+1}^{v} S_k\right)}{0.98} \sum_{j=1}^{w} S_{v+1,jC} R_{ij}. \end{aligned} \tag{E.6}$$

The partial derivatives necessary for estimating the standard error are:

$$\begin{aligned} \frac{\partial O_i}{\partial S_k} &= \frac{O_i}{S_k}, & k &= i+1, \ldots, v \\ \frac{\partial O_i}{\partial S_{v+1,jC}} &= \frac{\left(\prod_{k=i+1}^{v} S_k\right)}{0.98} R_{ij}, & j &= 1, \ldots, w \\ \frac{\partial O_i}{\partial R_{ij}} &= \frac{\left(\prod_{k=i+1}^{v} S_k\right)}{0.98} S_{v+1,jC}, & j &= 1, \ldots, w. \end{aligned}$$

E.1.3 Adult Upriver Survival

Several measures of adult upriver survival for tagged fish are given. Both measure the average perceived upriver survival of tagged adult salmon from Bonneville to Lower Granite. They measure only "perceived" upriver survival because they do not account for straying, fallback, or harvest, and they use the assumption of 100% detection at Lower Granite. The first measure is the average upriver survival of adults from a particular (juvenile) release group. This measure is calculated for the entire release group, incorporating both transported and nontransported fish ($S_{A_{Rel}}$), and also separately for nontransported fish ($S_{A_{NT}}$) and site-i transport fish (S_{A_i}). The final measure, $S_{A_{Ret}}$, is the average upriver survival of adults in a particular return year, combining fish from multiple release years. For Chinook, the indices j and m used in the formulas below should range from 2 to w, the oldest age class.

Adult Upriver Survival by Release Group

The overall upriver survival of adults from a particular release group, with all adult age classes combined and incorporating both transported and nontransported fish, is $S_{A_{Rel}}$. This performance measure represents perceived survival from Bonneville (site $v+1$) to Lower Granite (site $v+u$), and incorporates both transportation effects and the proportion of fish transported as juveniles. It does not account for adult straying or harvest rates. If Bonneville is not the first adult detection site, then $S_{A_{Rel}}$ is not reported. This measure is estimated without the jack age class (i.e., age-1-ocean fish) for Chinook salmon, and with the age-1-ocean fish for steelhead. Notation: $\sum_m = \sum_{m=2}^{w}$ for Chinook and $\sum_m = \sum_{m=1}^{w}$ for steelhead.

$$
\begin{aligned}
S_{A_{Rel}} &= Pr\big[\text{Survive from } v+1 \text{ to } v+u \mid \text{Reach } v+1, \text{ tagged fish}\big] \\
&= \frac{\sum_{j=1}^{w}\big[S_{v+1,jC}\cdots S_{v+u,jC}\big]}{\sum_{j=1}^{w} S_{v+1,jC}} \frac{R_{SYS(v+u)}}{R_{SYS(v+1)}},
\end{aligned} \tag{E.7}
$$

where $R_{SYS(v+1)}$ and $R_{SYS(v+u)}$ are versions of the systemwide T/I (Appendix E.3.3).

The partial derivatives necessary for estimating the standard error are (for $j = 1, \ldots, w$):

$$
\begin{aligned}
\frac{\partial S_{A_{Rel}}}{\partial S_{v+1,jC}} &= S_{A_{Rel}} \Bigg[\frac{S_{v+2,jC}\cdots S_{v+u,jC}}{\sum_m \big[S_{v+1,mC}\cdots S_{v+u,mC}\big]} - \frac{1}{\sum_m S_{v+1,mC}} + \frac{1}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial S_{v+1,jC}} \\
&\quad - \frac{1}{R_{SYS(v+1)}} \frac{\partial R_{SYS(v+1)}}{\partial S_{v+1,jC}} \Bigg] \\
\frac{\partial S_{A_{Rel}}}{\partial S_{ijC}} &= S_{A_{Rel}} \Bigg[\frac{S_{v+1,jC}\cdots S_{v+u,jC}}{S_{ijC}\sum_m \big[S_{v+1,mC},\cdots S_{v+u,mC}\big]} + \frac{1}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial S_{ijC}} \Bigg], \\
&\quad i = v+2, \ldots, v+u \\
\frac{\partial S_{A_{Rel}}}{\partial S_{ijT_n}} &= \begin{cases} \frac{S_{A_{Rel}}}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial S_{ijT_n}}, & i = v+2, \ldots, E; \quad n = 1, \ldots, v \\ 0, & i = v+1 \text{ or } i > E; \quad n = 1, \ldots, v \end{cases}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial S_{A_{Rel}}}{\partial p_i} &= S_{A_{Rel}} \Bigg[\frac{1}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial p_i} - \frac{1}{R_{SYS(v+1)}} \frac{\partial R_{SYS(v+1)}}{\partial p_i} \Bigg], \qquad i = 1, \ldots, v \\
\frac{\partial S_{A_{Rel}}}{\partial t_i} &= S_{A_{Rel}} \Bigg[\frac{1}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial t_i} - \frac{1}{R_{SYS(v+1)}} \frac{\partial R_{SYS(v+1)}}{\partial t_i} \Bigg], \qquad i = 1, \ldots, v \\
\frac{\partial S_{A_{Rel}}}{\partial R_{ij}} &= S_{A_{Rel}} \Bigg[\frac{1}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial R_{ij}} - \frac{1}{R_{SYS(v+1)}} \frac{\partial R_{SYS(v+1)}}{\partial R_{ij}} \Bigg], \qquad i = 1, \ldots, v
\end{aligned}
$$

Adult upriver survival by release group can be estimated separately for different groups of fish based on their juvenile migration method (e.g., inriver or transportation). The measure $S_{A_{NT}}$ is the average perceived adult upriver survival of all nontransported fish in a given release group, while S_{A_i} is the average perceived adult upriver survival of all dam-i transport fish in a given release group. For Chinook, the index j used in the formulas below should range from 2 to w, the oldest age class. Adult upriver survival for nontransported fish is:

$$
S_{A_{NT}} = \frac{\sum_{j=1}^{w}\left(\prod_{i=v+1}^{v+u} S_{ijC}\right)}{\sum_{j=1}^{w} S_{v+1,jC}}. \tag{E.8}
$$

The necessary partial derivatives for $S_{A_{NT}}$ are as follows ($j = 1, \ldots, w$):

$$\begin{aligned}
\frac{\partial S_{A_{NT}}}{\partial S_{v+1,jC}} &= \frac{1}{\sum_m S_{v+1,mC}} \left(\prod_{i=v+2}^{v+u} S_{ijC} - S_{A_{NT}} \right) \\
\frac{\partial S_{A_{NT}}}{\partial S_{ijC}} &= \frac{\prod_{l=v+1}^{v+u} S_{ljC}}{S_{ijC} \sum_m S_{v+1,mC}}, \qquad\qquad i = v+2, \ldots, v+u.
\end{aligned}$$

For $i = 1, \ldots, v$, adult upriver survival for dam-i transported fish is:

$$S_{A_i} = \frac{\sum_{j=1}^{w} \left(S_{v+1,jC} R_{ij} \prod_{k=v+2}^{v+u} S_{kjT_i} \right)}{\sum_{j=1}^{w} S_{v+1,jC} R_{ij}}. \tag{E.9}$$

The necessary partial derivatives for S_{A_i} are as follows ($j = 1, \ldots, w$):

$$\begin{aligned}
\frac{\partial S_{A_i}}{\partial S_{v+1,jC}} &= \frac{R_{ij}}{\sum_m S_{v+1,mC} R_{im}} \left(\prod_{k=v+2}^{v+u} S_{kjT_i} - S_{A_i} \right) \\
\frac{\partial S_{A_i}}{\partial S_{ljT_i}} &= \frac{S_{v+1,jC} R_{ij}}{S_{ljT_i} \sum_m S_{v+1,mC} R_{im}} \left(\prod_{k=v+2}^{v+u} S_{kjT_i} \right) \\
\frac{\partial S_{A_i}}{\partial R_{ij}} &= \frac{S_{v+1,jC}}{\sum_m S_{v+1,mC} R_{im}} \left(\prod_{k=v+2}^{v+u} S_{kjT_i} - S_{A_i} \right).
\end{aligned}$$

Adult Upriver Survival by Return Year

The average perceived upriver survival of adults in a particular return year is $S_{A_{Ret}}$. This performance measure represents perceived survival from Bonneville (site $v+1$) to Lower Granite (site $v+u$), incorporates both transported and nontransported fish, and combines adult data from multiple release years. It does not account for adult straying, fallback, or harvest. It includes the age-1-ocean fish for steelhead, but not for Chinook salmon. For Chinook, the index j used in the formulas below should range from 2 to w, the oldest age class, and the indices y and m should range from $J-3$ to $J-2$. If Bonneville is not the first adult site, then $S_{A_{Ret}}$ is not reported.

Defining $S_{A_{Ret}}$ analytically requires identification of the return year in question. Let $S_{A_{Ret(J)}}$ be $S_{A_{Ret}}$ for return year (calendar year) J. If the return year is understood, the subscript (J) will be dropped and the notation $S_{A_{Ret}}$ will be used.

For return year J,

$$\begin{aligned}
S_{A_{Ret(J)}} &= Pr\big[\text{Survive from } v+1 \text{ to } v+u \text{ in return year } J \mid \text{Reach } v+1 \text{ in return year } J\big] \\
&= \sum_{y=J-3}^{J-1} \omega_{y_J} S_{A_{y(J-y)}},
\end{aligned} \tag{E.10}$$

where ω_{y_J} is the proportion of adults detected in return year J that came from release year y, and

$S_{A_{y(J-y)}}$ is the perceived upriver survival for adults from release year y that returned in year J (i.e., as age-$(J-y)$-ocean adults). The weight ω_{y_J} is

$$\omega_{y_J} = \frac{U_{y_J}}{\sum_{m=J-3}^{J-1} U_{m_J}}, \tag{E.11}$$

where U_{y_J} is the number of unique adults detected in return year J that were released in year y.

The upriver survival from Bonneville to Lower Granite for age-j-ocean fish ($j = 1, \ldots, w$) from release year y is $S_{A_{y(j)}}$. This measure incorporates dam-specific transportation effects, as well as the proportion of fish transported at each dam.

$$S_{A_{y(j)}} = \frac{\left(\prod_{i=1}^{v}[1-p_i t_i]\right)\left(\prod_{i=v+2}^{v+u} S_{ijC}\right) + \sum_{i=1}^{v}\left[p_i t_i R_{ij}\left(\prod_{l=1}^{i-1}[1-p_l t_l]\right)\left(\prod_{l=v+2}^{E} S_{ljT_i}\right)\left(\prod_{l=E+1}^{v+u} S_{ljC}\right)\right]}{\prod_{i=1}^{v}[1-p_i t_i] + \sum_{i=1}^{v}\left[p_i t_i R_{ij}\left(\prod_{l=1}^{i-1}[1-p_l t_l]\right)\right]}, \tag{E.12}$$

where E is the adult site defining the extent of the transportation effects (see Appendix E.3).

The variance estimator of $\widehat{S_{A_{Ret(J)}}}$, conditional on the adult counts, is

$$\widehat{Var}\left(\widehat{S_{A_{Ret(J)}}}\right) = \sum_{y=J-3}^{J-1} \omega_{y_J}^2 \widehat{Var}\left(\widehat{S_{A_{y(J-y)}}}\right), \tag{E.13}$$

where $\widehat{Var}\left(\widehat{S_{A_{y(J-y)}}}\right)$ is estimated using the Delta Method (Eq. (E.1)) and the following partial derivatives. For $j = 1, \ldots, w$:

$$\frac{\partial S_{A_{y(j)}}}{\partial S_{ijC}} = \begin{cases} \dfrac{\left(\prod_{s=1}^{v}[1-p_s t_s]\right)\left(\prod_{l=v+2}^{v+u} S_{ljC}\right)}{S_{ijC}\left(\prod_{s=1}^{v}[1-p_s t_s] + \sum_{n=1}^{v}\left[p_n t_n R_{nj} \prod_{s=1}^{n-1}(1-p_s t_s)\right]\right)}, & \text{for } i = v+2, \ldots, E \\ \dfrac{S_{A_{y(j)}}}{S_{ijC}}, & \text{for } i = E+1, \ldots, v+u \end{cases}$$

$$\frac{\partial S_{A_{y(j)}}}{\partial S_{kjT_i}} = \frac{p_i t_i R_{ij}\left(\prod_{s=1}^{i-1}[1-p_s t_s]\right)\left(\prod_{l=v+2}^{E} S_{ljT_i}\right)\left(\prod_{l=E+1}^{v+u} S_{ljC}\right)}{S_{kjT_i}\left(\prod_{s=1}^{v}[1-p_s t_s] + \sum_{n=1}^{v}\left[p_n t_n R_{nj} \prod_{s=1}^{n-1}[1-p_s t_s]\right]\right)}, \qquad i = 1, \ldots, v; \quad k = v+2, \ldots, E$$

$$\frac{\partial S_{A_{y(j)}}}{\partial p_i} = \frac{-t_i\left(\prod_{s=1}^{v}[1-p_st_s]\right)\left[\prod_{l=v+2}^{v+u} S_{ljC} - S_{A_{y(j)}}\right]}{(1-p_it_i)\left(\prod_{s=1}^{v}[1-p_st_s] + \sum_{n=1}^{v}\left[p_nt_nR_{nj}\prod_{s=1}^{n-1}(1-p_st_s)\right]\right)}$$
$$+ \frac{t_iR_{ij}\left(\prod_{s=1}^{i}[1-p_st_s]\right)\left[\left(\prod_{l=v+2}^{E} S_{ljT_i}\right)\left(\prod_{l=E+1}^{v+u} S_{ljC}\right) - S_{A_{y(j)}}\right]}{(1-p_it_i)\left(\prod_{s=1}^{v}[1-p_st_s] + \sum_{n=1}^{v}\left[p_nt_nR_{nj}\prod_{s=1}^{n-1}(1-p_st_s)\right]\right)}$$
$$- \frac{t_i\sum_{n=i+1}^{v}\left\{p_nt_nR_{nj}\left(\prod_{s=1}^{n-1}[1-p_st_s]\right)\left[\left(\prod_{l=v+2}^{E} S_{ljT_s}\right)\left(\prod_{l=E+1}^{v+u} S_{ljC}\right) - S_{A_{y(j)}}\right]\right\}}{(1-p_it_i)\left(\prod_{s=1}^{v}[1-p_st_s] + \sum_{n=1}^{v}\left[p_nt_nR_{nj}\prod_{s=1}^{n-1}(1-p_st_s)\right]\right)},$$
$$i = 1, \ldots, v$$

$$\frac{\partial S_{A_{y(j)}}}{\partial t_i} = \frac{\partial S_{A_{y(j)}}}{\partial p_i}\frac{p_i}{t_i}, \qquad i = 1, \ldots, v$$

$$\frac{\partial S_{A_{y(j)}}}{\partial R_{ij}} = \frac{p_it_i\left(\prod_{s=1}^{i-1}[1-p_st_s]\right)\left[\left(\prod_{l=v+2}^{E} S_{ljT_i}\right)\left(\prod_{l=E+1}^{v+u} S_{ljC}\right) - S_{A_{y(j)}}\right]}{\prod_{s=1}^{v}[1-p_st_s] + \sum_{n=1}^{v}\left[p_nt_nR_{nj}\prod_{s=1}^{n-1}(1-p_st_s)\right]}, \qquad \text{for } i = 1, \ldots, v.$$

E.1.4 Smolt-to-Adult Return Ratio

The overall return probability to Lower Granite (site $v+u$) for the entire release group, regardless of juvenile migration method, is the smolt-to-adult return ratio, SAR. For Chinook, the index j used in the formulas below should range from 2 to w, the oldest age class. The smolt-to-adult return ratio is defined as follows:

$$SAR = S_2 \cdots S_v R_{SYS(v+u)} \sum_{j=1}^{w}\left[S_{v+1,jC} \cdots S_{v+u,jC}\right]. \qquad \text{(E.14)}$$

The partial derivatives necessary for estimating the standard error are ($j = 1, \ldots, w$):

$$\frac{\partial SAR}{\partial S_i} = \frac{SAR}{S_i}, \qquad i = 2, \ldots, v$$

$$\frac{\partial SAR}{\partial S_{ijC}} = \frac{SAR}{R_{SYS(v+u)}}\frac{\partial R_{SYS(v+u)}}{\partial S_{ijC}} + S_2 \cdots S_v R_{SYS(v+u)}\frac{S_{v+1,jC} \cdots S_{v+u,jC}}{S_{ijC}},$$
$$i = v+1, \ldots, v+u$$

$$\frac{\partial SAR}{\partial S_{ijT_n}} = \begin{cases} \frac{SAR}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial S_{ijT_n}} & i = v+2, \ldots, E; \quad n = 1, \ldots, v \\ 0, & i = v+1 \text{ or } i > E; \quad n = 1, \ldots, v \end{cases}$$

$$\frac{\partial SAR}{\partial p_i} = \frac{SAR}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial p_i}, \qquad i = 1, \ldots, v$$

$$\frac{\partial SAR}{\partial t_i} = \frac{SAR}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial t_i}, \qquad i = 1, \ldots, v$$

$$\frac{\partial SAR}{\partial R_{ij}} = \frac{SAR}{R_{SYS(v+u)}} \frac{\partial R_{SYS(v+u)}}{\partial R_{ij}}, \qquad i = 1, \ldots, v.$$

E.2 Proportion of Total Integrated Mortality for Nontransported Fish

The estimates of juvenile inriver survival (S_J), ocean return probability for nontransported fish (O_{NT}), and adult upriver survival for nontransported fish ($S_{A_{NT}}$) are combined to estimate the proportion of the total integrated mortality for nontransported fish (during migration from Lower Granite back to Lower Granite) that is accounted for by each migratory stage. The integrated mortality accounted for by the juvenile inriver migration from LGR to BON is defined as

$$\gamma_J = -\ln(S_J).$$

Similarly, the integrated mortality accounted for by the ocean life stage (from BON to BON) is

$$\gamma_O = -\ln(O_{NT}),$$

and the integrated mortality accounted for by the adult upriver migration (from BON to LGR) is

$$\gamma_A = -\ln(S_{A_{NT}}).$$

The total integrated mortality is $\gamma = \gamma_J + \gamma_O + \gamma_A$. The proportion of total integrated mortality accounted for by the juvenile inriver migration is

$$\mu_J = \frac{\gamma_J}{\gamma}.$$

Similarly, the proportion of total integrated mortality accounted for by the ocean life stage is $\mu_O = \gamma_O/\gamma$, and the proportion of total integrated mortality accounted for by the adult upriver migration is $\mu_A = \gamma_A/\gamma$.

Variance estimators for the μ_J, μ_O, and μ_A measures are defined as follows:

$$\widehat{Var}\left(\widehat{\mu_J}\right)=\left(\frac{1}{\widehat{\gamma}}\right)^2\left\{\left(\frac{1-\widehat{\mu_J}}{\widehat{S_J}}\right)^2\widehat{Var}\left(\widehat{S_J}\right)+\left(\frac{\widehat{\mu_J}}{\widehat{O_{NT}}}\right)^2\widehat{Var}\left(\widehat{O_{NT}}\right)+\left(\frac{\widehat{\mu_J}}{\widehat{S_{A_{NT}}}}\right)^2\widehat{Var}\left(\widehat{S_{A_{NT}}}\right)\right.$$
$$\left.-\frac{2\widehat{\mu_J}\left(1-\widehat{\mu_J}\right)}{\widehat{S_J}}\left[\frac{\widehat{Cov}\left(\widehat{S_J},\widehat{O_{NT}}\right)}{\widehat{O_{NT}}}+\frac{\widehat{Cov}\left(\widehat{S_J},\widehat{S_{A_{NT}}}\right)}{\widehat{S_{A_{NT}}}}\right]+\frac{2\widehat{\mu_J^2}}{\widehat{O_{NT}}\widehat{S_{A_{NT}}}}\widehat{Cov}\left(\widehat{O_{NT}},\widehat{S_{A_{NT}}}\right)\right\}$$

$$\widehat{Var}\left(\widehat{\mu_O}\right)=\left(\frac{1}{\widehat{\gamma}}\right)^2\left\{\left(\frac{1-\widehat{\mu_O}}{\widehat{O_{NT}}}\right)^2\widehat{Var}\left(\widehat{O_{NT}}\right)+\left(\frac{\widehat{\mu_O}}{\widehat{S_J}}\right)^2\widehat{Var}\left(\widehat{S_J}\right)+\left(\frac{\widehat{\mu_O}}{\widehat{S_{A_{NT}}}}\right)^2\widehat{Var}\left(\widehat{S_{A_{NT}}}\right)\right.$$
$$\left.-\frac{2\widehat{\mu_O}\left(1-\widehat{\mu_O}\right)}{\widehat{O_{NT}}}\left[\frac{\widehat{Cov}\left(\widehat{S_J},\widehat{O_{NT}}\right)}{\widehat{S_J}}+\frac{\widehat{Cov}\left(\widehat{O_{NT}},\widehat{S_{A_{NT}}}\right)}{\widehat{S_{A_{NT}}}}\right]+\frac{2\widehat{\mu_O^2}}{\widehat{S_J}\widehat{S_{A_{NT}}}}\widehat{Cov}\left(\widehat{S_J},\widehat{S_{A_{NT}}}\right)\right\}$$

$$\widehat{Var}\left(\widehat{\mu_A}\right)=\left(\frac{1}{\widehat{\gamma}}\right)^2\left\{\left(\frac{1-\widehat{\mu_A}}{\widehat{S_{A_{NT}}}}\right)^2\widehat{Var}\left(\widehat{S_{A_{NT}}}\right)+\left(\frac{\widehat{\mu_A}}{\widehat{S_J}}\right)^2\widehat{Var}\left(\widehat{S_J}\right)+\left(\frac{\widehat{\mu_A}}{\widehat{O_{NT}}}\right)^2\widehat{Var}\left(\widehat{O_{NT}}\right)\right.$$
$$\left.-\frac{2\widehat{\mu_A}\left(1-\widehat{\mu_A}\right)}{\widehat{S_{A_{NT}}}}\left[\frac{\widehat{Cov}\left(\widehat{S_J},\widehat{S_{A_{NT}}}\right)}{\widehat{S_J}}+\frac{\widehat{Cov}\left(\widehat{O_{NT}},\widehat{S_{A_{NT}}}\right)}{\widehat{O_{NT}}}\right]+\frac{2\widehat{\mu_A^2}}{\widehat{S_J}\widehat{O_{NT}}}\widehat{Cov}\left(\widehat{S_J},\widehat{O_{NT}}\right)\right\},$$

where $\widehat{Var}\left(\widehat{S_J}\right)$, $\widehat{Var}\left(\widehat{O_{NT}}\right)$, and $\widehat{Var}\left(\widehat{S_{A_{NT}}}\right)$ are defined as in Sections E.1.1, E.1.2, and E.1.3, respectively, and $\widehat{Cov}\left(\widehat{S_J},\widehat{O_{NT}}\right)$, $\widehat{Cov}\left(\widehat{S_J},\widehat{S_{A_{NT}}}\right)$, and $\widehat{Cov}\left(\widehat{O_{NT}},\widehat{S_{A_{NT}}}\right)$ are defined below. For Chinook, the indices j and m used in the formulas below should range from 2 to w, the oldest age class.

$$\widehat{Cov}\left(\widehat{S_J},\widehat{O_{NT}}\right)=\sum_{i=2}^{v}\sum_{j=1}^{w}\frac{S_J}{S_i}\widehat{Cov}\left(\widehat{S}_i,\widehat{S_{v+1,jC}}\right),$$
$$\widehat{Cov}\left(\widehat{S_J},\widehat{S_{A_{NT}}}\right)=\sum_{i=2}^{v}\sum_{k=v+2}^{v+u}\sum_{j=1}^{w}\left(\frac{S_J}{S_i}\right)\left(\frac{S_{v+2,jC}\cdots S_{v+u,jC}}{S_{kjC}}\right)\widehat{Cov}\left(\widehat{S}_i,\widehat{S_{kjC}}\right),$$
$$\widehat{Cov}\left(\widehat{O_{NT}},\widehat{S_{A_{NT}}}\right)=\sum_{k=v+2}^{v+u}\sum_{j=1}^{w}\sum_{m=1}^{w}\frac{S_{v+2,mC}\cdots S_{v+u,mC}}{S_{kmC}}\widehat{Cov}\left(\widehat{S_{v+1,jC}},\widehat{S_{kmC}}\right).$$

All estimators should be evaluated at the maximum likelihood estimate of the parameter vector. Estimates of pairwise covariances of model parameters are provided by Program ROSTER in the estimated variance-covariance matrix.

E.3 Transport-Inriver Ratios

Transport-inriver (T/I) ratios (Buchanan, Skalski and Smith 2006), are a class of transportation effect measures. In general, the T/I is the ratio of the return probability to Lower Granite for transported fish to that of corresponding nontransported fish. We report two types of T/I measure: a dam-specific, "isolated" measure that represents the effect of transportation from a single dam, unconfounded by the rest of the transportation system, and a systemwide measure that incorporates transportation probabilities and effects at all dams, as well as juvenile survival and ocean survival. Each type of T/I can be calculated based on adult returns to either Bonneville or Lower Granite. While only those based on return probabilities to Lower Granite are reported, T/I ratios based on return probabilities to Bonneville are used in calculating other performance measures, so both versions of the T/I ratios are defined here. For each of the following performance measures, let k represent the adult site to which return probabilities are calculated, with $k = v + 1$ (Bonneville) or $k = v + u$ (Lower Granite). Additionally, let E represent the adult site that is the extent of the transportation effects assumed in the model, with $E = v + 1, \ldots, v + u$. There are no effects of juvenile transportation on the adult migration through reaches upriver of site E.

E.3.1 Age- and Dam-specific T/I

The age- and dam-specific T/I is the model parameter R_{ij}. It represents the relative age-j-ocean return probability to Bonneville of fish transported from dam i to that of fish that were not transported there, as if the nontransported fish had no further opportunity for transportation. These age- and dam-specific measures are not reported. However, other performance measures depend on these values, calculated either with return probabilities to Bonneville or with return probabilities to Lower Granite. If juvenile transportation from dam i results in effects on the adult upriver migration ($E > v + 1$), then the value of the age- and dam-specific T/I will depend on the adult site to which return probabilities are calculated. Thus, we generalize the R_{ij} parameter to incorporate adult upriver effects and adult return probabilities either to site $k = v+1$ (Bonneville) or to site $k = v+u$ (Lower Granite). The generalized parameter is $R_{ij(k)}$, the age- and dam-specific T/I for returns to adult site k. For Chinook, the index j used in the formulas below should range from 2 to w, the oldest age class. In general, for $j = 1, \ldots, w$, R_{ij} is defined as follows:

$$\begin{aligned} R_{ij(k)} &= \frac{Pr\big[\text{Adult return to site } k \text{ in year } j \mid \text{Transported at dam } i\big]}{Pr\big[\text{Adult return to site } k \text{ in year } j \mid \text{Inriver, no other transportation}\big]} \\ &= \begin{cases} R_{ij} \frac{S_{v+2,jT_i} \cdots S_{kjT_i}}{S_{v+2,jC} \cdots S_{kjC}} & \text{for } k = v+u \\ R_{ij} & \text{for } k = v+1 \end{cases} \end{aligned} \tag{E.15}$$

The partial derivatives necessary for estimating the standard error are (for $i = 1, \ldots, v$ and $j = 1, \ldots, w$):

$$\frac{\partial R_{ij(k)}}{\partial R_{ij}} = \frac{R_{ij(k)}}{R_{ij}} \quad \text{for } k, E = v+1, \ldots, v+u$$

$$\frac{\partial R_{ij(k)}}{\partial S_{ljT_i}} = \begin{cases} \frac{R_{ij(k)}}{S_{ljT_i}} & \text{for } l = v+2, \ldots, \min(k, E); \quad k, E = v+2, \ldots, v+u \\ 0 & \text{for } \min(l, k, E) = v+1 \text{ or } l > E; \quad k = v+1, \ldots, v+u \end{cases}$$

$$\frac{\partial R_{ij(k)}}{\partial S_{ljC}} = \begin{cases} \frac{-R_{ij(k)}}{S_{ljC}} & \text{for } l = v+2, \ldots, \min(k, E); \quad k, E = v+2, \ldots, v+u \\ 0 & \text{for } \min(l, k, E) = v+1 \text{ or } l > E; \quad k = v+1, \ldots, v+u \end{cases}$$

E.3.2 Dam-specific T/I

The dam-specific T/I for dam i, $R_{i(k)}$, is the relative adult return probability to adult site k for fish transported from dam i, compared to the return probability to site k for fish not transported at dam i, as if they had no further opportunities for transportation. The value $R_{i(k)}$ measures the effect of juvenile transportation from dam i on site-k return probabilities, unconfounded by effects of transportation at any dam downstream of dam i. It is a compilation of the age- and dam-specific T/I ratios, $R_{ij(k)}$. For $k = v+1$ or $k = v+u$, $R_{i(k)}$ is defined as follows (with j ranging from 2 to w for Chinook):

$$\begin{aligned} R_{i(k)} &= \frac{Pr\big[\text{Adult return to site } k \mid \text{Transported at dam } i\big]}{Pr\big[\text{Adult return to site } k \mid \text{Inriver, no other transportation}\big]} \\ &= \frac{\sum_{j=1}^{w} S_{v+1,jC} \cdots S_{kjC} R_{ij(k)}}{\sum_{j=1}^{w} S_{v+1,jC} \cdots S_{kjC}}, \qquad i = 1, \ldots, v. \end{aligned} \tag{E.16}$$

The estimates of dam-specific T/I values presented in this report reflect return probabilities to Lower Granite (i.e., for $k = v+u$). For Chinook, the indices j and m used in the formulas below should range from 2 to w, the oldest age class. The partial derivatives necessary for estimating the standard error are ($i = 1, \ldots, v$ and $j = 1, \ldots, w$):

$$\frac{\partial R_{i(k)}}{\partial S_{ljC}} = \begin{cases} \frac{-R_{i(k)} S_{v+1,jC} \cdots S_{kjC}}{S_{ljC} \sum_{m=1}^{w} \left[S_{v+1,mC} \cdots S_{kmC}\right]} & \text{for } l = v+2, \ldots, \min(k, E); \quad k, E = v+2, \ldots, v+u \\ \\ \frac{S_{v+1,jC} \cdots S_{kjC} \left(R_{ij(k)} - R_{i(k)}\right)}{S_{ljC} \sum_{m=1}^{w} \left[S_{v+1,mC} \cdots S_{kmC}\right]} & \text{for } \min(l, k, E) = v+1 \text{ or } l > E; \quad k = v+1, \ldots, v+u \end{cases}$$

$$\frac{\partial R_{i(k)}}{\partial R_{ij}} = \frac{R_{ij(k)} S_{v+1,jC} \cdots S_{kjC}}{R_{ij} \sum_{m=1}^{w} \left[S_{v+1,mC} \cdots S_{kmC} \right]} \qquad \text{for } k, E = v+1, \ldots, v+u$$

$$\frac{\partial R_{i(k)}}{\partial S_{ljT_i}} = \begin{cases} \frac{R_{ij(k)} S_{v+1,jC} \cdots S_{kjC}}{S_{ljT_i} \sum_{m=1}^{w} \left[S_{v+1,mC} \cdots S_{kmC} \right]} & \text{for } l = v+2, \ldots, \min(k, E); \quad k, E = v+2, \ldots, v+u \\ \\ 0 & \text{for } \min(l, k, E) = v+1 \text{ or } l > E; \quad k = v+1, \ldots, v+u \end{cases}$$

E.3.3 Systemwide T/I

The systemwide measure of transportation effects is $R_{SYS(k)}$, the ratio of the return probability to adult site k for the entire release group with the transportation system, compared to what that return probability would have been without the transportation system. This measure incorporates the dam-specific transportation effects, as well as the proportion of fish transported at each dam and the river and ocean survival of nontransported fish. For $k = v + 1$ and $k = v + u$, $R_{SYS(k)}$ is defined as follows:

$$\begin{aligned} R_{SYS(k)} &= \frac{Pr\left[\text{Adult return to site } k \mid \text{Transportation system}\right]}{Pr\left[\text{Adult return to site } k \mid \text{No transportation system}\right]} \\ &= \sum_{i=1}^{v} \left\{ p_i t_i R_{i(k)} \prod_{n=1}^{i-1} \left(1 - p_n t_n\right) \right\} + \prod_{i=1}^{v} \left(1 - p_i t_i\right). \end{aligned} \tag{E.17}$$

Some of the partial derivatives used to estimate the standard error for $R_{SYS(k)}$ depend on the measure $RC_{i(k)}$, a contextual dam-specific T/I for dam i, where the control group may be transported downstream of dam i. The measure $RC_{i(k)}$ is defined:

$$\begin{aligned} RC_{i(k)} &= \frac{Pr\left[\text{Adult return to site } k \mid \text{Transported from dam } i\right]}{Pr\left[\text{Adult return to site } k \mid \text{Pass dam } i \text{ inriver}\right]} \\ &= \frac{R_{i(k)}}{\sum_{n=i+1}^{v} \left\{ p_n t_n R_{n(k)} \left[\prod_{s=i+1}^{n-1} \left(1 - p_s t_s\right) \right] \right\} + \prod_{s=i+1}^{v} \left(1 - p_s t_s\right)}. \end{aligned} \tag{E.18}$$

For Chinook, the indices j and m used in the formulas below should range from 2 to w, the oldest age class. The necessary partial derivatives for $R_{SYS(k)}$ are (for $j = 1, \dots, w$):

$$\frac{\partial R_{SYS(k)}}{\partial p_i} = \frac{t_i R_{i(k)} \big(RC_{i(k)} - 1\big) \prod_{s=1}^{i-1} \big(1 - p_s t_s\big)}{RC_{i(k)}}, \qquad i = 1, \dots, v; \quad k, E = v+1, \dots, v+u$$

$$\frac{\partial R_{SYS(k)}}{\partial t_i} = \frac{p_i R_{i(k)} \big(RC_{i(k)} - 1\big) \prod_{s=1}^{i-1} \big(1 - p_s t_s\big)}{RC_{i(k)}}, \qquad i = 1, \dots, v; \quad k, E = v+1, \dots, v+u$$

$$\frac{\partial R_{SYS(k)}}{\partial S_{ijC}} = \begin{cases} \dfrac{-\Big[R_{SYS(k)} - \prod_{s=1}^{v} \Big(1 - p_s t_s\Big)\Big] S_{v+1,jC} \cdots S_{kjC}}{S_{ijC} \sum_{m=1}^{w} \Big[S_{v+1,mC} \cdots S_{kmC}\Big]}, \\ \qquad \text{for } i = v+2, \dots, \min(k, E); \quad k, E = v+2, \dots, v+u \\ \\ \dfrac{S_{v+1,jC} \cdots S_{kjC} \sum_{n=1}^{v} \Big\{p_n t_n \Big(R_{nj(k)} - R_{n(k)}\Big) \prod_{s=1}^{n-1} \Big(1 - p_s t_s\Big)\Big\}}{S_{ijC} \sum_{m=1}^{w} \Big[S_{v+1,mC} \cdots S_{kmC}\Big]}, \\ \qquad \text{for } \min(i, k, E) = v+1 \text{ or } i > E; \quad k = v+1, \dots, v+u \end{cases}$$

$$\frac{\partial R_{SYS(k)}}{\partial S_{ijT_n}} = \begin{cases} \dfrac{p_n t_n R_{nj(k)} S_{v+1,jC} \cdots S_{kjC} \prod_{s=1}^{n-1} \Big(1 - p_s t_s\Big)}{S_{ijT_n} \sum_{m=1}^{w} \Big[S_{v+1,mC} \cdots S_{kmC}\Big]}, \\ \qquad \text{for } n = 1, \dots, v; \quad i = v+2, \dots, \min(k, E); \quad k, E = v+2, \dots, v+u \\ \\ 0, \qquad \text{for } n = 1, \dots, v; \quad \min(i, k, E) = v+1 \text{ or } i > E; \quad k = v+1, \dots, v+u \end{cases}$$

$$\frac{\partial R_{SYS(k)}}{\partial R_{ij}} = \frac{p_i t_i R_{ij(k)} S_{v+1,jC} \cdots S_{kjC} \prod_{s=1}^{i-1} \big(1 - p_s t_s\big)}{R_{ij} \sum_{m=1}^{w} \big[S_{v+1,mC} \cdots S_{kmC}\big]}, \quad i = 1, \dots, v; \quad k, E = v+1, \dots, v+u$$

E.4 Differential Post-Bonneville Mortality (D)

The measure D is often referred to as differential post-Bonneville mortality, delayed mortality or delayed differential mortality. This measure is the ratio of the post-Bonneville survival probability to Lower Granite for transported fish to the post-Bonneville survival probability for nontransported fish. It includes ocean survival and perceived adult upriver survival. As with the T/I ratios, D can be defined on a dam-specific basis that reflects effects of transportation at a single dam, or as a systemwide measure that incorporates all transport sites. Both types are reported here. Let E represent the adult site that is the extent of the transportation effects assumed in the model, with $E = v+1, \dots, v+u$. For Chinook, the index j used in the formulas below should range from 2 to w, the oldest age class.

E.4.1 Dam-specific D

The performance measure D_i is an isolated measure of differential mortality specifically for juvenile dam i, analogous to the isolated dam-specific T/I, R_i (i.e., $R_{i(v+u)}$). The measure D_i is the ratio of post-Bonneville survival to Lower Granite for fish transported at dam i, relative to fish that passed dam i inriver and had no further opportunity for transportation. In cases where the final juvenile detection site is upriver from Bonneville (i.e., $v \neq$ BON), the measure D_i uses extrapolated juvenile inriver survival to account for inriver juvenile survival from the final juvenile site to Bonneville. In the following, the notation R_i denotes the performance measure $R_{i(v+u)}$.

$$D_i = \begin{cases} \frac{R_i \prod_{y=i+1}^{v} S_y}{S_B} & \text{if } v = \text{BON}, \\ \frac{R_i \left(\prod_{y=2}^{v} S_y\right)^{\frac{x-x_i}{x_v}}}{S_B} & \text{if } v \neq \text{BON}, \end{cases} \tag{E.19}$$

where S_B is the survival probability on the barge during transportation, and where x is the number of units (detection sites, hydroelectric projects, or RKM) between Lower Granite and Bonneville, x_i is the number of units between Lower Granite and site i, and x_v is the number of units between Lower Granite and site v. The type of units used should be the same as the units used in the extrapolation of juvenile inriver survival (S_J) and the ocean return probability (O_{NT}), with $x = 5$ used if a per-site extrapolation is used and John Day is a detection site.

For Chinook, the index j used in the formulas below should range from 2 to w, the oldest age class. Partial derivatives for D_i are (for $i = 1, \ldots, v$; $j = 1, \ldots, w$; and $E = v+1, \ldots, v+u$):

$$\frac{\partial D_i}{\partial S_B} = -\frac{D_i}{S_B}$$

$$\frac{\partial D_i}{\partial S_k} = \begin{cases} \frac{D_i}{S_k}, & \text{for } v = \text{BON} \\ \frac{D_i}{S_k}\left(\frac{x-x_i}{x_v}\right), & \text{for } v \neq \text{BON} \end{cases} \qquad k = i+1, \ldots, v$$

$$\frac{\partial D_i}{\partial R_{ij}} = \frac{D_i}{R_i}\frac{\partial R_i}{\partial R_{ij}}$$

$$\frac{\partial D_i}{\partial S_{ljC}} = \frac{D_i}{R_i}\frac{\partial R_i}{\partial S_{ljC}} \qquad l = v+1, \ldots, v+u$$

$$\frac{\partial D_i}{\partial S_{ljT_i}} = \frac{D_i}{R_i}\frac{\partial R_i}{\partial S_{ljT_i}} \qquad l = v+2, \ldots, E$$

E.4.2 Systemwide D

The performance measure D_{SYS} is a systemwide measure of differential mortality, incorporating all transport sites and transportation rates and effects at each dam. The measure D_{SYS} is the ratio of post-Bonneville return probabilities to Lower Granite for transported fish to that of nontransported fish. Notation: R_i refers to $R_{i(v+u)}$, and RC_i refers to $RC_{i(v+u)}$.

$$D_{SYS} = \frac{S_1\left(\prod_{i=2}^{v} S_i\right)^{\frac{x}{y}}\left(\sum_{n=1}^{v}\left[\left(\prod_{i=1}^{n-1}\left[1-p_i t_i\right]\right)p_n t_n R_n\right]\right)}{S_B\sum_{n=1}^{v}\left(\left(\prod_{i=1}^{n-1} S_i\left[1-p_i t_i\right]\right)S_n p_n t_n\right)}, \tag{E.20}$$

where x and y are as defined for Equations (E.2) and (E.5). For Chinook, the indices j and m used in the formulas below should range from 2 to w, the oldest age class. Partial derivatives necessary for estimating the standard error are (for $j = 1, \ldots, w$ and $E = v+1, \ldots, v+u$):

$$\frac{\partial D_{SYS}}{\partial S_i} = \frac{D_{SYS}}{S_i}\left[\frac{x}{y} - \frac{\sum_{n=i}^{v}\left[S_n p_n t_n\left(\prod_{k=1}^{n-1} S_k(1-p_k t_k)\right)\right]}{\sum_{n=1}^{v}\left[S_n p_n t_n\left(\prod_{k=1}^{n-1} S_k(1-p_k t_k)\right)\right]}\right] \qquad i = 2, \ldots, v$$

$$\frac{\partial D_{SYS}}{\partial p_i} = \frac{D_{SYS} S_i t_i\left(\prod_{k=1}^{i-1} S_k(1-p_k t_k)\right)\alpha_i}{\sum_{n=1}^{v}\left[S_n p_n t_n\left(\prod_{k=1}^{n-1} S_k(1-p_k t_k)\right)S_B\right]}, \qquad i = 1, \ldots, v$$

where

$$\alpha_i = \left(\frac{\prod_{k=i+1}^{v} S_k}{D_{SYS}}\right)\left(\frac{R_i}{RC_i}(RC_i - 1) + \prod_{k=i+1}^{v}(1-p_k t_k)\right) - S_B\left(1 - \sum_{n=i+1}^{v}\left[S_n p_n t_n \prod_{k=i+1}^{n-1} S_k(1-p_k t_k)\right]\right)$$

$$\frac{\partial D_{SYS}}{\partial t_i} = \frac{\partial D_{SYS}}{\partial p_i}\frac{p_i}{t_i} \qquad i = 1, \ldots, v$$

$$\frac{\partial D_{SYS}}{\partial R_{ij}} = \frac{D_{SYS} p_i t_i\left(\prod_{k=1}^{i-1}(1-p_k t_k)\right)R_{ij} S_{v+1,jC}\cdots S_{v+u,jC}}{R_{ij}\sum_{m=1}^{w}\left[S_{v+1,mC}\cdots S_{v+u,mC}\right]\sum_{n=1}^{v}\left[p_n t_n R_n \prod_{k=1}^{n-1}(1-p_k t_k)\right]} \qquad i = 1, \ldots, v$$

$$\frac{\partial D_{SYS}}{\partial S_{ijC}} = D_{SYS} \frac{\sum_{n=1}^{v} \left[p_n t_n \frac{\partial R_n}{\partial S_{njC}} \prod_{k=1}^{n-1} (1 - p_k t_k) \right]}{\sum_{n=1}^{v} \left[p_n t_n R_n \prod_{k=1}^{n-1} (1 - p_k t_k) \right]} \qquad i = v+1, \ldots, v+u;$$

$$\frac{\partial D_{SYS}}{\partial S_{ijT_n}} = \frac{D_{SYS} p_n t_n \frac{\partial R_n}{\partial S_{ijT_n}} \prod_{k=1}^{n-1} (1 - p_k t_k)}{\sum_{s=1}^{v} \left[p_s t_s R_s \prod_{k=1}^{s-1} (1 - p_k t_k) \right]} \qquad i = v+2, \ldots, v+u; \; n = 1, \ldots, v$$

$$\frac{\partial D_{SYS}}{\partial S_B} = \frac{-D_{SYS}}{S_B}$$

E.5 Heuristic Performance Measures

In cases where it is impossible to fit the full statistical model in Program ROSTER because of sparse adult detections of nontransported fish, it is possible to use estimates of upriver juvenile parameters (e.g., $\widehat{S}_1$, $\widehat{p}_1$, $\widehat{t}_1$, $\widehat{S}_2$, etc.) together with tallies of adult detections at LGR to devise heuristic "non-ROSTER" performance measures. The form of the performance measures depends on the number of transport sites. In the following formulas, all model parameters should be evaluated at their MLE from the juvenile portion of the statistical model in Program ROSTER (or equivalently, from the CJS model).

E.5.1 Heuristic Dam-Specific T/I

This method is appropriate in cases with only a single transport dam. Additional transport sites will complicate the heuristic dam-specific T/I. The single-transport-dam estimator is sufficient for the data analyzed in this report. Notation: R_i refers to $R_{i(v+u)}$.

When the full statistical model is unavailable, it is necessary to estimate R_i using a modification of the Ricker (1975) method. The statistic h_i is the number of smolts transported at dam i. Let AT be the number of these transported fish that are detected at LGR as adults (including age-1-ocean fish for steelhead but not for Chinook). We can estimate the number of smolts that reach the tailrace of dam i as $N \times \prod_{k=1}^{i} \left(\widehat{S}_k \widehat{x}_k \right)$, where $x_k = 1 - p_k + p_k (1 - c_k)(1 - t_k)$ is the probability getting past dam k without being censored or transported there, conditional on reaching dam k. Because dam i is the only transport dam, $x_k = 1 - p_k c_k$ for $k \neq i$. Let AC be the number of these nontransported (i.e., "control") fish that are detected at LGR as adults. Then we can estimate the dam-specific T/I ratio for dam i heuristically as follows:

$$\widehat{R}_i = \frac{AT}{h_i} \frac{N \times \prod_{k=1}^{i} \left(\widehat{S}_k \widehat{x}_k \right)}{AC}. \tag{E.21}$$

The heuristic estimator $\widehat{R_i}$ is valid for both tagged and untagged fish, under the assumption that tagged and untagged fish respond to transportation in the same way.

The variance of $\widehat{R_i}$ includes both sampling uncertainty and binomial error from AT and AC. The only case where the heuristic $\widehat{R_i}$ is used in this report is for summer Chinook salmon released in 2001, with transportation at LGR only. Thus, the variance of $\widehat{R_i}$ is given for the special case of $i = 1$ only.

$$\widehat{Var}\left(\widehat{R_1}\right) = \left(\frac{N\widehat{S}_1\widehat{x}_1}{h_1}\right)^2 \left[(1+\psi)\,\widehat{Var}\left(\frac{AT}{AC}\right) + \psi\left(\frac{AT}{AC}\right)^2\right], \tag{E.22}$$

where

$$\widehat{Var}\left(\frac{AT}{AC}\right) = \frac{AT\left(N\widehat{S}_1\widehat{x}_1 - AC\right)}{N\widehat{S}_1\widehat{x}_1 AC^3} + \frac{1}{AC^2}\frac{AT}{h_1}\left(h_1 - AT\right) - \frac{AT\left(h_1 - AT\right)}{h_1}\frac{N\widehat{S}_1\widehat{x}_1 - AC}{N\widehat{S}_1\widehat{x}_1 AC^3}, \tag{E.23}$$

and where

$$\psi = \frac{\widehat{Var}\left(\widehat{S}_1\right)}{\widehat{S}_1^2} - \frac{2\left[1-\left(1-\widehat{c}_1\right)\left(1-\widehat{t}_1\right)\right]\widehat{Cov}\left(\widehat{S}_1,\widehat{p}_1\right)}{\widehat{S}_1\widehat{x}_1} + \frac{\left[1-\left(1-\widehat{c}_1\right)\left(1-\widehat{t}_1\right)\right]^2\widehat{Var}\left(\widehat{p}_1\right) + \widehat{p}_1^2\left(1-\widehat{t}_1\right)^2\widehat{Var}\left(\widehat{c}_1\right) + \widehat{p}_1^2\left(1-\widehat{c}_1\right)^2\widehat{Var}\left(\widehat{t}_1\right)}{\widehat{x}_1^2}.$$

E.5.2 Heuristic Systemwide T/I

This method is appropriate in cases with only a single transport dam. Additional transport sites will complicate the heuristic dam-specific T/I ratio. The single-transport-dam estimator is sufficient for the data analyzed in this report.

The systemwide T/I based on the heuristic model has the same form as if it were based on the full statistical model, but it uses the heuristic measure of the dam-specific T/I:

$$\widehat{R_{SYS}} = \widehat{p}_i\widehat{t}_i\widehat{R}_i + \left(1 - \widehat{p}_i\widehat{t}_i\right), \tag{E.24}$$

where $\widehat{R_i}$ is defined in Eq. (E.21). The heuristic estimator $\widehat{R_{SYS}}$ is valid for tagged fish. Under the assumption that all untagged fish that are detected at dam i are also transported there, the analogous estimator for untagged fish is R^U_{SYS}, where

$$\widehat{R^U_{SYS}} = \widehat{p}_i\widehat{R}_i + \left(1 - \widehat{p}_i\right). \tag{E.25}$$

The variance estimator of $\widehat{R_{SYS}}$ is given for the case $i = 1$:

$$\widehat{Var}\left(\widehat{R_{SYS}}\right) = \widehat{Var}\left(\frac{AT}{AC}\right)\left[\psi_1 + \left(\frac{N\widehat{S}_1\widehat{p}_1\widehat{t}_1\widehat{x}}{h_1}\right)^2\right] + \left(\frac{AT}{AC}\right)^2 \psi_1 + \psi_2, \tag{E.26}$$

where $\widehat{Var}\left(\frac{AT}{AC}\right)$ is given in Eq. (E.23), and where

$$\begin{aligned}\psi_1 = &\left(\frac{N\widehat{S}_1\widehat{p}_1\widehat{t}_1}{h_1}\right)^2 \left[\left(\frac{\widehat{x}_1}{\widehat{S}_1}\right)^2 \widehat{Var}\left(\widehat{S}_1\right) + \left(\frac{\widehat{x}_1 - \widehat{p}_1\left[1-(1-\widehat{c}_1)\left(1-\widehat{t}\right)\right]}{\widehat{p}_1}\right)^2 \widehat{Var}\left(\widehat{p}_1\right) + \right.\\
&\left[\widehat{p}_1\left(1-\widehat{t}_1\right)\right]^2 \widehat{Var}\left(\widehat{c}_1\right) + \left(\frac{\widehat{x}_1 - \widehat{p}_1\widehat{t}_1\left(1-\widehat{c}_1\right)}{\widehat{t}_1}\right)^2 \widehat{Var}\left(\widehat{t}_1\right) + \\
&\left.\frac{2\widehat{x}_1\left(\widehat{x}_1 - \widehat{p}_1\left[1-(1-\widehat{c}_1)\left(1-\widehat{t}_1\right)\right]\right)}{\widehat{S}_1\widehat{p}_1}\widehat{Cov}\left(\widehat{S}_1, \widehat{p}_1\right)\right],\\
\psi_2 = &\,\widehat{t}_1^2\widehat{Var}\left(\widehat{p}_1\right) + \widehat{p}_1^2\widehat{Var}\left(\widehat{t}_1\right) - \frac{N\widehat{S}_1\widehat{p}_1\widehat{t}_1}{h_1}\frac{AT}{AC}\left[\frac{2\widehat{t}_1\left(\widehat{x}_1 - \widehat{p}_1\left[1-(1-\widehat{c}_1)\left(1-\widehat{t}_1\right)\right]\right)}{\widehat{p}_1}\widehat{Var}\left(\widehat{p}_1\right) + \right.\\
&\left.\frac{2\widehat{p}_1\left[\widehat{x}_1 - \widehat{p}_1\widehat{t}_1\left(1-\widehat{c}_1\right)\right]}{\widehat{t}_1}\widehat{Var}\left(\widehat{t}_1\right) + \frac{2\widehat{t}_1\widehat{x}_1}{\widehat{S}_1}\widehat{Cov}\left(\widehat{S}_1, \widehat{p}_1\right)\right].\end{aligned}$$

The variance of $\widehat{R_{SYS}^U}$ is estimated by

$$\widehat{Var}\left(\widehat{R_{SYS}^U}\right) = \widehat{Var}\left(\frac{AT}{AC}\right)\left[\psi_1^U + \left(\frac{N\widehat{S}_1\widehat{p}_1\widehat{t}_1}{h_1}\right)^2\right] + \psi_1^U\left(\frac{AT}{AC}\right)^2 + \psi_2^U, \tag{E.27}$$

where $\widehat{Var}\left(\frac{AT}{AC}\right)$ is given in Eq. (E.23), and where

$$\begin{aligned}\psi_1^U = &\left(\frac{N\widehat{S}_1\widehat{p}_1}{h_1}\right)^2 \left[\left(\frac{\widehat{x}_1}{\widehat{S}_1}\right)^2 \widehat{Var}\left(\widehat{S}_1\right) + \left(\frac{\widehat{x}_1 - \widehat{p}_1\left[1-(1-\widehat{c}_1)\left(1-\widehat{t}_1\right)\right]}{\widehat{p}_1}\right)^2 \widehat{Var}\left(\widehat{p}_1\right) + \right.\\
&\left[\widehat{p}_1\left(1-\widehat{t}_1\right)\right]^2 \widehat{Var}\left(\widehat{c}_1\right) + \left[\widehat{p}_1\left(1-\widehat{c}_1\right)\right]^2 \widehat{Var}\left(\widehat{t}_1\right) + \\
&\left.\frac{2\widehat{x}_1\left(\widehat{x}_1 - \widehat{p}_1\left[1-(1-\widehat{c}_1)\left(1-\widehat{t}_1\right)\right]\right)}{\widehat{S}_1\widehat{p}_1}\widehat{Cov}\left(\widehat{S}_1, \widehat{p}_1\right)\right],\\
\psi_2^U = &\,\widehat{Var}\left(\widehat{p}_1\right) - 2\frac{N\widehat{S}_1}{h_1}\frac{AT}{AC}\left[\left(\widehat{x}_1 - \widehat{p}_1\left[1-(1-\widehat{c}_1)\left(1-\widehat{t}\right)\right]\right)\widehat{Var}\left(\widehat{p}_1\right) + \frac{\widehat{p}_1\widehat{x}_1}{\widehat{S}_1}\widehat{Cov}\left(\widehat{S}_1, \widehat{p}_1\right)\right].\end{aligned}$$

E.5.3 Heuristic SAR

No Transport Sites

As usual, the smolt-adult return ratio (SAR) is defined to be the probability of returning from LGR as a juvenile to LGR as an adult. If A is defined to be the number of adults detected at LGR (including age-1-ocean adults for steelhead but not for Chinook), then SAR can be estimated by

$$\widehat{SAR} = \frac{A}{N\widehat{S}_1\left(1-\widehat{p}_1\widehat{c}_1\right)}, \tag{E.28}$$

where $N\widehat{S}_1\left(1-\widehat{p}_1\widehat{c}_1\right)$ is the estimate of the number of juveniles that reached the tailrace of LGR. The estimate $\widehat{SAR}$ has two sources of uncertainty that must be accounted for in devising a variance estimator: sampling variability in estimating S_1, p_1, and c_1, and binomial variability in A. These two sources of variability complicate the variance estimator. The variance of $\widehat{SAR}$ can be estimated as follows:

$$\widehat{Var}\left(\widehat{SAR}\right) = \theta A\left(1-\frac{A}{N\widehat{S}_1\left(1-\widehat{p}_1\widehat{c}_1\right)}+A\right)+\frac{A}{\left(N\widehat{S}_1\left(1-\widehat{p}_1\widehat{c}_1\right)\right)^2}\left(1-\frac{A}{N\widehat{S}_1\left(1-\widehat{p}_1\widehat{c}_1\right)}\right),$$

where

$$\theta = \left(\frac{1}{N\widehat{S}_1\left(1-\widehat{p}_1\widehat{c}_1\right)}\right)^2\left[\frac{\widehat{Var}\left(\widehat{S}_1\right)}{\widehat{S}_1^2}+\frac{\widehat{c}_1^2\widehat{Var}\left(\widehat{p}_1\right)+\widehat{p}_1^2\widehat{Var}\left(\widehat{c}_1\right)+2\widehat{p}_1\widehat{c}_1\widehat{Cov}\left(\widehat{p}_1,\widehat{c}_1\right)}{\left(1-\widehat{p}_1\widehat{c}_1\right)^2}- 2\frac{\widehat{c}_1\widehat{Cov}\left(\widehat{S}_1,\widehat{p}_1\right)+\widehat{p}_1\widehat{Cov}\left(\widehat{S}_1,\widehat{c}_1\right)}{\widehat{S}_1\left(1-\widehat{p}_1\widehat{c}_1\right)}\right].$$

Because there is no smolt transportation, the measure SAR is suitable for both tagged and untagged fish, under the assumption that tagged and untagged fish have common survival. This measure can be estimated either with or without jacks by including or excluding, respectively, the jacks in the adult count A.

Single Transport Sites

The smolt-to-adult return ratio, SAR, can be estimated heuristically using the transport and nontransport SARs. Let SAR_T be the SAR of the transport fish from transport dam i to LGR, and let SAR_I be the SAR of the nontransport (inriver) fish from dam i to LGR:

$$\widehat{SAR}_T = \frac{AT}{h_i},$$

$$\widehat{SAR}_I = \frac{AC}{N \prod_{k=1}^{i} \left(\widehat{S}_k \widehat{x}_k \right)}.$$

Then the overall SAR from LGR as a juvenile to LGR as an adult can be estimated heuristically by

$$\widehat{SAR} = \left(\prod_{k=2}^{i} \widehat{S}_k \right) \left(\widehat{p}_i \widehat{t}_i \widehat{SAR}_T + \left(1 - \widehat{p}_i \widehat{t}_i\right) \widehat{SAR}_I \right). \tag{E.29}$$

The estimator $\widehat{SAR}$ from Eq. (E.29) is valid for tagged fish. The analogous measure for untagged fish is

$$\widehat{SAR^U} = \left(\prod_{k=2}^{i} \widehat{S}_k \right) \left(\widehat{p}_i \widehat{SAR}_T + (1 - \widehat{p}_i) \widehat{SAR}_I \right). \tag{E.30}$$

These measures can be estimated either with or without jacks by including or excluding, respectively, the age-1-ocean fish in the adult counts AT and AC.

For the case where $i = 1$, we have

$$\widehat{SAR}_T = \frac{AT}{h_1}, \qquad \widehat{SAR}_I = \frac{AC}{N \widehat{S}_1 \widehat{x}_1}, \tag{E.31}$$

and

$$\begin{aligned} \widehat{SAR} &= \widehat{p}_1 \widehat{t}_1 \widehat{SAR}_T + \left(1 - \widehat{pt}\right) \widehat{SAR}_I, \\ \widehat{SAR^U} &= \widehat{p}_1 \widehat{SAR}_T + (1 - \widehat{p}_1) \widehat{SAR}_I. \end{aligned}$$

The variance of $\widehat{SAR}$ from Eq. (E.29) for the case where $i = 1$ can be estimated by

$$\begin{aligned} \widehat{Var}\left(\widehat{SAR}\right) = {} & \widehat{Var}\left(\widehat{SAR}_T\right) \left[\left(\widehat{p}_1 \widehat{t}_1\right)^2 + \psi_T \right] + \widehat{Var}\left(\widehat{SAR}_I\right) \left[\left(1 - \widehat{p}_1 \widehat{t}_1\right)^2 + \psi_I \right] \\ & + \psi_I \widehat{SAR}_I^2 + \psi_T \widehat{SAR}_T^2 + 2 \psi_{TI} \widehat{SAR}_T \widehat{SAR}_I, \end{aligned} \tag{E.32}$$

where

$$\widehat{Var}\left(\widehat{SAR}_T\right) = \frac{\widehat{SAR}_T \left(1 - \widehat{SAR}_T\right)}{h_1}, \tag{E.33}$$

$$\widehat{Var}\left(\widehat{SAR}_I\right) = \frac{\widehat{SAR}_I \left(1 - \widehat{SAR}_I\right)}{N \widehat{S}_1 \widehat{x}_1}, \tag{E.34}$$

and

$$
\begin{aligned}
\psi_T &= \hat{t}_1^2 \widehat{Var}\left(\hat{p}_1\right) + \hat{p}_1^2 \widehat{Var}\left(\hat{t}_1\right), \\
\psi_I &= \hat{t}_1^2 \widehat{Var}\left(\hat{p}_1\right) + \hat{p}_1^2 \widehat{Var}\left(\hat{t}_1\right) + \frac{\left(1-\hat{p}_1\hat{t}_1\right)^2}{\hat{S}_1^2} \widehat{Var}\left(\hat{S}_1\right) - \\
&\quad \frac{2\left(1-\hat{p}_1\hat{t}_1\right)}{\hat{x}_1}\left(\hat{t}_1\left[1-\left(1-\hat{c}_1\right)\left(1-\hat{t}_1\right)\right]\widehat{Var}\left(\hat{p}_1\right) + \hat{p}_1^2\left(1-\hat{c}_1\right)\widehat{Var}\left(\hat{t}_1\right)\right) + \\
&\quad \frac{2\left(1-\hat{p}_1\hat{t}_1\right)}{\hat{s}_1}\left(\hat{t}_1 - \frac{\left(1-\hat{p}_1\hat{t}_1\right)\left[1-\left(1-\hat{c}_1\right)\left(1-\hat{t}_1\right)\right]}{\hat{x}_1}\right)\widehat{Cov}\left(\hat{S}_1, \hat{p}_1\right) + \\
&\quad \frac{\left(1-\hat{p}_1\hat{t}_1\right)^2}{\hat{x}_1^2}\left(\left[1-\left(1-\hat{c}_1\right)\left(1-\hat{t}_1\right)\right]^2\widehat{Var}\left(\hat{p}_1\right) + \hat{p}_1^2\left(1-\hat{t}_1\right)^2\widehat{Var}\left(\hat{c}_1\right) + \hat{p}_1^2\left(1-\hat{c}_1\right)^2\widehat{Var}\left(\hat{t}_1\right)\right), \\
\psi_{TI} &= -\left(\hat{t}_1^2\widehat{Var}\left(\hat{p}_1\right) + \hat{p}_1^2\widehat{Var}\left(\hat{t}_1\right)\right) - \frac{\hat{t}_1\left(1-\hat{p}_1\hat{t}_1\right)}{\hat{S}_1}\widehat{Cov}\left(\hat{S}_1, \hat{p}_1\right) + \\
&\quad \frac{\left(1-\hat{p}_1\hat{t}_1\right)}{\hat{x}_1}\left(\hat{t}_1\left[1-\left(1-\hat{c}_1\right)\left(1-\hat{t}_1\right)\right]\widehat{Var}\left(\hat{p}_1\right) + \hat{p}_1^2\left(1-\hat{c}_1\right)\widehat{Var}\left(\hat{t}_1\right)\right).
\end{aligned}
$$

The variance of $\widehat{SAR}^U$ from Eq. (E.30) for the case where $i = 1$ is estimated by:

$$
\begin{aligned}
\widehat{Var}\left(\widehat{SAR}^U\right) &= \left(\hat{p}_1^2 + \widehat{Var}\left(\hat{p}_1\right)\right)\widehat{Var}\left(\widehat{SAR}_T\right) + \left(\left(1-\hat{p}_1\right)^2 + \psi_I^U\right)\widehat{Var}\left(\widehat{SAR}_I\right) + \\
&\quad \widehat{Var}\left(\hat{p}_1\right)\widehat{SAR}_T^2 + \psi_I^U\widehat{SAR}_I^2 + 2\psi_{TI}^U\widehat{SAR}_T\widehat{SAR}_I,
\end{aligned}
\tag{E.35}
$$

where $\widehat{SAR}_T$ and $\widehat{SAR}_I$ are defined in Eq. (E.31), $\widehat{Var}\left(\widehat{SAR}_T\right)$ and $\widehat{Var}\left(\widehat{SAR}_T\right)$ are defined in Eqs. (E.33) and (E.34), and where

$$
\begin{aligned}
\psi_I^U &= \frac{\left(1-\hat{p}_1\right)^2}{\hat{S}_1^2}\widehat{Var}\left(\hat{S}_1\right) + \left(1 - \frac{\left[1-\hat{p}_1\right]\left[1-\left(1-\hat{c}_1\right)\left(1-\hat{t}_1\right)\right]}{\hat{x}_1}\right)^2\widehat{Var}\left(\hat{p}_1\right) - \\
&\quad \frac{2\left(1-\hat{p}_1\right)^2\left[1-\left(1-\hat{c}_1\right)\left(1-\hat{t}_1\right)\right]}{\hat{S}_1\hat{x}_1}\widehat{Cov}\left(\hat{S}_1, \hat{p}_1\right) + \\
&\quad \frac{\hat{p}_1^2\left(1-\hat{p}_1\right)^2}{\hat{x}_1^2}\left[\left(1-\hat{t}_1\right)^2\widehat{Var}\left(\hat{c}_1\right) + \left(1-\hat{c}_1\right)^2\widehat{Var}\left(\hat{t}_1\right)\right], \\
\psi_{TI}^U &= \left[\frac{\left(1-\hat{p}_1\right)\left[1-\left(1-\hat{c}_1\right)\left(1-\hat{t}_1\right)\right]}{\hat{x}_1} - 1\right]\widehat{Var}\left(\hat{p}_1\right) - \frac{\left(1-\hat{p}_1\right)}{\hat{S}_1}\widehat{Cov}\left(\hat{S}_1, \hat{p}_1\right).
\end{aligned}
$$

E.5.4 Heuristic Adult Upriver Survival

Perceived adult upriver survival is the probability of reaching LGR (and being detected there), conditional on having reached BON as an adult. Two basic measures of perceived adult upriver survival are given. The first measure, $S_{A_{Rel}}$, combines adult upriver survival from the different return years (adult age classes), and gives an average value for the release group as a whole. The second measure, $S_{A_{Ret}}$, combines adult data from fish from different release years, and estimates the average perceived upriver survival of adults in a particular year. The heuristic measures $S_{A_{Rel}}$ and $S_{A_{Ret}}$ defined here are analogous to the measures defined in Appendix E.1.3, but do not distinguish between non-detection at BON and mortality before reaching BON as an adult. These heuristic (non-ROSTER) estimates of perceived adult upriver survival are based entirely on counts of adults at BON and LGR, and do not depend on estimates of model parameters.

The measures $S_{A_{Rel}}$ and $S_{A_{Ret}}$ defined below are valid whether or not there is smolt transportation. In the case of transportation, these measures are valid only for tagged fish if tagged and untagged fish are transported at different rates. If there is smolt transportation, then there are no analogous measures of adult upriver survival for untagged fish without using the full statistical model. For Chinook, the indices j and m and all ranges of adult age classes used in the formulas below should range from 2 to w, the oldest age class.

Heuristic Perceived Adult Upriver Survival by Release Group

Define U_j to be the number of unique adults detected in adult age class j ($j = 1, \dots, w$). For conciseness of notation, define $\sum_j U_j \equiv \sum_{j=1}^{w} U_j$, and define $\sum_m U_m$ analogously. Let A_j be the number of unique adults detected at BON in adult age class j, and let BL_j be the number of adults detected at both BON and LGR in adult age class j. Then perceived adult upriver survival can be estimated by

$$\widehat{S_{A_{Rel}}} = \frac{1}{\sum_j U_j} \sum_j \frac{U_j BL_j}{A_j}. \tag{E.36}$$

Perceived adult upriver survival by release group and juvenile migration method (e.g., nontransported ($S_{A_{NT}}$) or dam-i transport (S_{A_i})) may be estimated by restricting the counts U_j, A_j, and BL_j to either nontransported adults or dam-i transported adults, respectively.

The variance of $\widehat{S_{A_{Rel}}}$ can be estimated using the Delta Method by

$$\widehat{Var}\left(\widehat{S_{A_{Rel}}}\right) = \left(\boldsymbol{G}^T \boldsymbol{V} \boldsymbol{G}\right),$$

where $\boldsymbol{G}$ is the vector of partial derivatives of S_A with respect to the statistics U_j, A_j, and BL_j ($j = 1, \dots, w$), and where $\boldsymbol{V}$ is the variance-covariance matrix of the vector of statistics $(U_1, \dots, U_w, A_1, \dots, A_w, BL_1, \dots, BL_w)$. The vector $\boldsymbol{G}$ has the form

$$\boldsymbol{G}^T = \left(\frac{\partial \widehat{S_{A_{Rel}}}}{\partial U_1}, \dots \frac{\partial \widehat{S_{A_{Rel}}}}{\partial U_w}, \frac{\partial \widehat{S_{A_{Rel}}}}{\partial A_1}, \dots, \frac{\partial \widehat{S_{A_{Rel}}}}{\partial A_w}, \frac{\partial \widehat{S_{A_{Rel}}}}{\partial BL_1}, \dots, \frac{\partial \widehat{S_{A_{Rel}}}}{\partial BL_w} \right),$$

where

$$\begin{aligned}
\frac{\partial \widehat{S_{A_{Rel}}}}{\partial U_j} &= \frac{1}{\sum_m U_m}\left(\frac{BL_j}{A_j} - \widehat{S_{A_{Rel}}}\right), \\
\frac{\partial \widehat{S_{A_{Rel}}}}{\partial A_j} &= \frac{-U_j BL_j}{A_j^2 \sum_m U_m}, \\
\frac{\partial \widehat{S_{A_{Rel}}}}{\partial BL_j} &= \frac{1}{\sum_m U_m}\frac{U_j}{A_j}.
\end{aligned} \tag{E.37}$$

The estimated variance-covariance matrix $\boldsymbol{V}$ has entries as follows:

$$\begin{aligned}
Var\left(U_j\right) &= N\pi_j\left(1-\pi_j\right) \\
Var\left(A_j\right) &= N\pi_j P_j\left(1-\pi_j P_j\right) \\
Var\left(BL_j\right) &= N\pi_j P_j S_{A_j}\left(1-\pi_j P_j S_{A_j}\right) \\
Cov\left(U_j, U_k\right) &= -N\pi_j\pi_k, \text{ for } j \neq k \\
Cov\left(A_j, A_k\right) &= -N\pi_j P_j \pi_k P_k, \text{ for } j \neq k \\
Cov\left(BL_j, BL_k\right) &= -N\pi_j P_j S_{A_j}\pi_k P_k S_{A_k}, \text{ for } j \neq k \\
Cov\left(U_j, A_k\right) &= \begin{cases} -N\pi_j\pi_k P_k \text{ for } j \neq k \\ N\pi_j\left(1-\pi_j\right)P_j \text{ for } j = k \end{cases} \\
Cov\left(U_j, BL_k\right) &= \begin{cases} -N\pi_j\pi_k P_k S_{A_k} \text{ for } j \neq k \\ N\pi_j\left(1-\pi_j\right)P_j S_{A_j} \text{ for } j = k \end{cases} \\
Cov\left(A_j, BL_k\right) &= \begin{cases} -N\pi_j P_j\pi_k P_k S_{A_k} \text{ for } j \neq k \\ N\pi_j P_j\left(1-\pi_j P_j\right)S_{A_j} \text{ for } j = 1, \end{cases}
\end{aligned}$$

where

$$\begin{aligned}
\pi_j &= \frac{U_j}{N} \\
P_j &= \frac{A_j}{U_j} \\
S_{Aj} &= \frac{BL_j}{A_j}.
\end{aligned}$$

Heuristic Perceived Adult Upriver Survival by Return Year

The estimator of the measure $S_{A_{Ret}}$ has the same form when estimated heuristically as when estimated from ROSTER parameters (cf. Eq. (E.10)). Also as in Eq. (E.10), $S_{A_{Ret(J)}}$ is $S_{A_{Ret}}$ for return year (calendar year) J. For Chinook, the indices y and m should range from $J-3$ to $J-2$, and the index j should range from 2 to w, the oldest age class. In general for return year J,

$$S_{A_{Ret(J)}} = \sum_{y=J-3}^{J-1} \omega_{y_J} S_{A_{y(J-y)}}, \tag{E.38}$$

where ω_{y_J} is the proportion of adults detected in return year J that came from release year y, and $S_{A_{y(J-y)}}$ is the perceived upriver survival for adults from release year y that returned in year J (i.e., as age-$(J-y)$-ocean adults). As for the ROSTER measure, the weight ω_{y_J} is

$$\omega_{y_J} = \frac{U_{y_J}}{\sum_{m=J-3}^{J-1} U_{m_J}}, \tag{E.39}$$

where U_{y_J} is the number of unique adults detected in return year J that were released in year y.

The upriver survival from Bonneville to Lower Granite for age-j-ocean fish ($j = 1, \ldots, w$) from release year y is $S_{A_{y(j)}}$. Instead of estimating $S_{A_{y(j)}}$ in terms of model parameters as in Appendix E.1.3, we estimate $S_{A_{y(j)}}$ as for the heuristic estimator of $S_{A_{Rel}}$ above:

$$S_{A_{y(j)}} = \frac{BL_{y(j)}}{A_{y(j)}},$$

where $BL_{y(j)}$ is the number of adults detected at both Bonneville and Lower Granite in year j that were released in year y, and $A_{y(j)}$ is the number of (unique) adults detected at Bonneville in year j that were released in year y.

The variance of the heuristic estimator of $S_{A_{Ret(J)}}$ can be estimated by

$$\widehat{Var}\left(\widehat{S_{A_{Ret(J)}}}\right) = \sum_{y=J-3}^{J-1} \omega_{y_J}^2 \widehat{Var}\left(\widehat{S_{A_{y(J-y)}}}\right),$$

where

$$\widehat{Var}\left(\widehat{S_{A_{y(J-y)}}}\right) = \frac{\widehat{S_{A_{y(J)}}}\left(1 - \widehat{S_{A_{y(J)}}}\right)}{A_{y(J)}}.$$

Appendix F

Notes on Fitting the Model

Tables F.1 through F.5 identify certain key notes about fitting the model to the various data sets. In particular, survival parameters that were fixed (instead of estimated) are identified, as well as the effect of this practice on interpreting results. Also, any age classes or records that were omitted are identified as well. More extensive notes on how specific data sets were analyzed are available online at `http://www.cbr.washington.edu/trends/roster.php` (see meta data for chosen performance measure, release group, and year).

Table F.1: Notes on fitting model to data sets for the spring Chinook salmon release groups from the Clearwater Basin (release area CLR).

Release Year	Notes
1996	No BON juvenile detection site, so S_J extrapolated by RKM.
1997	No BON juvenile detection site, so S_J extrapolated by project.
1998	Fixed S_6 to 0.999999; standard error on S_J, SAR, D_{LGR}, and D_{SYS} will be underestimated.
1999	
2000	
2001	
2002	Fixed S_{C71}, S_{C92}, and S_{C93} to 1; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2004, 2005) will be underestimated.
2003	

Table F.2: Notes on fitting model to data sets for the spring Chinook salmon release groups from the Snake River, excluding the Clearwater River (release area SNK).

Release Year	Notes
1996	No BON juvenile detection site, so S_J extrapolated by site.
1997	
1998	
1999	Fixed S_6 to 0.999999; standard error on S_J, SAR, D_{LGR}, D_{LGS}, and D_{SYS} will be underestimated.
2000	Censored record of single age-4-ocean fish at its final juvenile detection.
2001	
2002	Fixed S_{T911}, S_{C93}, S_{T931} to 0.999999; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2005), R_{LGR}, R_{LGS}, R_{SYS}, D_{LGR}, D_{LGR}, and D_{SYS} will be underestimated.
2003	Fixed S_{T911}, S_{T931}, S_{C91}, S_{C92}, and S_{C93} to 0.999999; standard error on SAR, $S_{A_{Rel}}$, $S_{A_{Ret}}$ (for 2005 and 2006), R_{LGR}, R_{LGS}, R_{SYS}, D_{LGR}, D_{LGS}, and D_{SYS} will be underestimated.

Table F.3: Notes on fitting model to data sets for the spring Chinook salmon release groups from the Snake River, including the Clearwater River (release area SNB).

Release Year	Notes
1996	No BON juvenile detection site, so S_J extrapolated by project.
1997	No BON juvenile detection site, so S_J, D_{LGR}, and D_{SYS} extrapolated by site.
1998	
1999	Fixed S_6 to 0.999999; standard error on S_J, SAR, D_{LGR}, D_{LGS}, and D_{SYS} will be underestimated.
2000	Removed record of single age-4-ocean fish.
2001	
2002	Fixed S_{C93}, S_{T931}, S_{T911}, and S_{C92} to 0.999999; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2004 and 2005), R_{LGR}, R_{LGS}, R_{SYS}, D_{LGR}, D_{LGR}, and D_{SYS} will be underestimated.
2003	Fixed S_{C93}, S_{T911}, S_{T912}, S_{T931}, and S_{T932} to 0.999999; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2006), R_{LGR}, R_{LGS}, R_{SYS}, D_{LGR}, D_{LGR}, and D_{SYS} will be underestimated.

Table F.4: Notes on fitting model to data sets for the summer Chinook salmon release groups.

Release Year	Notes
1996	No JD or BON juvenile detection site, so S_4 is survival in last juvenile reach. $\widehat{S}_4 >> 1$, so computed heuristic performance measures. Model parameters S_1, p_1, and c_1 were estimated using the ROSTER model.
1997	
1998	No BON juvenile detection site, so S_J, D_{LGR}, and D_{SYS} extrapolated by site.
1999	
2000	Censored record of single age-4-ocean fish at its final juvenile detection.
2001	$\widehat{S}_6 >> 1$, so computed heuristic performance measures. Model parameters S_1, p_1, c_1, and t_1 were estimated using the ROSTER model.
2002	Fixed S_{C83} and S_{C93} to 1; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2005) will be underestimated.
2003	Fixed S_{C91}, S_{C93}, S_{T931}, S_{T921}, and λ_{C1} to 1; standard error on SAR, $S_{A_{Rel}}$, $S_{A_{Ret}}$ (for 2005 and 2006), R_{LGR}, R_{SYS}, D_{LGR}, and D_{SYS} will be underestimated.

Table F.5: Notes on fitting model to data sets for the steelhead release groups.

Release Year	Notes
1996	No BON juvenile detection site, so S_J extrapolated by RKM.
1997	
1998	$\widehat{S}_6 >> 1$, so computed heuristic performance measures. Model parameters S_1, p_1, and c_1 were estimated using the ROSTER model.
1999	
2000	
2001	Too few adults for ROSTER analysis. Computed heuristic performance measures. Fit CJS model (with removals) to reduced data set including juvenile sites LGR, LGS, and all later detections pooled (3 fields in detection history). Used UW software USER to estimate S_1, p_1, and c_1. For $S_{A_{Rel}}$ and $S_{A_{Ret}}$, included the 107 smolts that had been removed from release group because of residualization. These 107 smolts resulted in 5 adults.
2002	Fixed S_{C83}, S_{C93}, and S_{C92} to 0.999999; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2004 and 2005) will be underestimated.
2003	Fixed S_{C91} and S_{C92} to 0.999999; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2005) will be underestimated.

Appendix G

Tables of Estimated Performance Measures

The annual regional release groups are composed of multiple smaller releases (Table C.1-C.5). Three types of spring Chinook releases were analyzed for each release year, categorized by release area. The smallest groups were released in the Clearwater River Basin, denoted “CLR.” Larger release groups were released in the Snake River Basin, excluding the Clearwater Basin; this release area is denoted “SNK.” These two groups were pooled to form a larger Snake River Basin group, including the Clearwater Basin; this combined release area is denoted “SNB.” Summer Chinook salmon and steelhead release groups are designated only “SNB.”

G.1 SAR

Table G.1: Estimated smolt-to-adult return ratios from Lower Granite to Lower Granite for PIT-tagged fish (i.e., “tagged SAR,” SAR). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook SAR does not include the age-1-ocean age class (“jacks”), while steelhead SAR does include the age-1-ocean age class.

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	0.0015	0.0032	0.0103	0.0107	0.0100	0.0015	0.0049	0.0021	0.0055
		(0.0003)	(0.0007)	(0.0005)	(0.0005)	(0.0005)	(0.0003)	(0.0003)	(0.0002)	(0.0015)
Spring Chinook	SNK	0.0013	0.0051	0.0078	0.0153	0.0182	0.0044	0.0072	0.0034	0.0078
		(0.0003)	(0.0009)	(0.0006)	(0.0003)	(0.0007)	(0.0006)	(0.0002)	(0.0002)	(0.0021)
Spring Chinook	SNB	0.0014	0.0050	0.0087	0.0139	0.0148	0.0034	0.0068	0.0031	0.0071
		(0.0002)	(0.0005)	(0.0004)	(0.0003)	(0.0004)	(0.0004)	(0.0002)	(0.0001)	(0.0018)
Summer Chinook	SNB	0.0011	0.0081	0.0151	0.0219	0.0259	0.0051	0.0093	0.0054	0.0115
		(0.0003)	(0.0016)	(0.0013)	(0.0009)	(0.0010)	(0.0004)	(0.0005)	(0.0004)	(0.0031)
Steelhead	SNB	0.0019	0.0013	0.0051	0.0062	0.0098	0.0003	0.0070	0.0045	0.0045
		(0.0004)	(0.0002)	(0.0005)	(0.0004)	(0.0006)	(0.0001)	(0.0005)	(0.0004)	(0.0011)

Table G.2: Estimated smolt-to-adult return ratios from Lower Granite to Lower Granite for PIT-tagged fish, had they been transported as untagged fish (i.e., "untagged SAR," SAR^U). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook SAR does not include the age-1-ocean age class ("jacks"), while steelhead SAR does include the age-1-ocean age class.

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	0.0015	0.0032	0.0104	0.0107	0.0106	0.0026	0.0049	0.0022	0.0058
		(0.0003)	(0.0007)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0003)	(0.0003)	(0.0015)
Spring Chinook	SNK	0.0013	0.0052	0.0089	0.0201	0.0203	0.0084	0.0080	0.0035	0.0095
		(0.0003)	(0.0009)	(0.0007)	(0.0008)	(0.0008)	(0.0012)	(0.0004)	(0.0002)	(0.0025)
Spring Chinook	SNB	0.0014	0.0051	0.0093	0.0173	0.0160	0.0063	0.0073	0.0033	0.0082
		(0.0002)	(0.0005)	(0.0005)	(0.0006)	(0.0005)	(0.0008)	(0.0003)	(0.0002)	(0.0020)
Summer Chinook	SNB	0.0011	0.0083	0.0178	0.0240	0.0296	0.0113	0.0093	0.0058	0.0134
		(0.0003)	(0.0016)	(0.0016)	(0.0012)	(0.0012)	(0.0009)	(0.0005)	(0.0004)	(0.0034)
Steelhead	SNB	0.0019	0.0013	0.0051	0.0062	0.0098	0.0003	0.0070	0.0045	0.0045
		(0.0004)	(0.0002)	(0.0005)	(0.0004)	(0.0006)	(0.0001)	(0.0005)	(0.0004)	(0.0011)

G.2 Juvenile Inriver Survival

Table G.3: Estimated juvenile inriver survival from Lower Granite to Bonneville (S_J). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean.

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	0.3737	0.3026	0.5752	0.5779	0.5630	0.3129	0.6416	0.5899	0.4921
		(0.3017)	(0.2308)	(0.0327)	(0.0619)	(0.0715)	(0.1529)	(0.0835)	(0.1400)	(0.0488)
Spring Chinook	SNK	0.8326	0.6159	0.6024	0.7528	0.7024	0.3795	0.7246	0.5819	0.6490
		(0.4563)	(0.2110)	(0.1194)	(0.0169)	(0.0633)	(0.1155)	(0.0555)	(0.0609)	(0.0488)
Spring Chinook	SNB	0.5841	0.5086	0.6379	0.7229	0.6481	0.3554	0.7314	0.5920	0.5976
		(0.3000)	(0.1514)	(0.0852)	(0.0129)	(0.0480)	(0.0997)	(0.0470)	(0.0553)	(0.0432)
Summer Chinook	SNB	-	0.7177	0.7343	0.5184	0.6045	-	0.6509	0.6771	0.6505
		(-)	(0.2566)	(0.1702)	(0.0400)	(0.0491)	(-)	(0.0619)	(0.0799)	(0.0326)
Steelhead	SNB	0.2597	0.4590	-	0.4787	0.2387	-	0.3038	0.3828	0.3538
		(0.2443)	(0.2361)	(-)	(0.0656)	(0.0245)	(-)	(0.0367)	(0.0517)	(0.0417)

G.3 Ocean Return Probabilities

Table G.4: Estimated ocean return probabilities for nontransported fish (O_{NT}). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook ocean return probability does not include the age-1-ocean age class ("jacks"), while steelhead ocean return probability does include the age-1-ocean age class.

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Spring Chinook	CLR	0.0241	0.0228	0.0015	0.0088	0.0039	0.0122
		(0.0032)	(0.0032)	(0.0009)	(0.0013)	(0.0011)	(0.0048)
Spring Chinook	SNK	0.0196	0.0250	0.0023	0.0114	0.0057	0.0128
		(0.0012)	(0.0025)	(0.0009)	(0.0010)	(0.0007)	(0.0042)
Spring Chinook	SNB	0.0201	0.0240	0.0020	0.0106	0.0053	0.0124
		(0.0009)	(0.0020)	(0.0007)	(0.0008)	(0.0006)	(0.0042)
Summer Chinook	SNB	0.0473	0.0377	-	0.0178	0.0081	0.0277
		(0.0043)	(0.0035)	(-)	(0.0020)	(0.0012)	(0.0090)
Steelhead	SNB	0.0167	0.0528	-	0.0271	0.0153	0.0280
		(0.0029)	(0.0063)	(-)	(0.0039)	(0.0026)	(0.0087)

Table G.5: Estimated ocean return probabilities for fish transported from LGR (O_{LGR}). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook ocean return probability does not include the age-1-ocean age class ("jacks").

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Spring Chinook	CLR	-	0.0209	0.0045	-	0.0040	0.0098
		(-)	(0.0015)	(0.0005)	(-)	(0.0008)	(0.0055)
Spring Chinook	SNK	0.0324	0.0391	0.0137	0.0142	0.0063	0.0211
		(0.0021)	(0.0017)	(0.0008)	(0.0013)	(0.0004)	(0.0062)
Spring Chinook	SNB	0.0305	0.0315	0.0098	0.0127	0.0060	0.0181
		(0.0018)	(0.0012)	(0.0005)	(0.0010)	(0.0004)	(0.0054)
Summer Chinook	SNB	-	0.0545	-	-	0.0099	0.0322
		(-)	(0.0025)	(-)	(-)	(0.0010)	(0.0223)
Steelhead	SNB	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)

Table G.6: Estimated ocean return probabilities for fish transported from LGS (O_{LGS}). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook ocean return probability does not include the age-1-ocean age class ("jacks").

Species	**Release Area**	**Release Year** 1999	2000	2001	2002	2003	**Average**
Spring Chinook	CLR	-	0.0169	-	-	-	0.0169
		(-)	(0.0018)	(-)	(-)	(-)	(-)
Spring Chinook	SNK	0.0342	0.0287	0.0058	0.0106	0.0045	0.0168
		(0.0027)	(0.0021)	(0.0011)	(0.0012)	(0.0005)	(0.0062)
Spring Chinook	SNB	0.0304	0.0235	0.0055	0.0103	0.0045	0.0148
		(0.0022)	(0.0014)	(0.0008)	(0.0009)	(0.0005)	(0.0052)
Summer Chinook	SNB	0.0403	-	-	-	-	0.0403
		(0.0031)	(-)	(-)	(-)	(-)	(-)
Steelhead	SNB	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)

G.4 Adult Upriver Survival by Release Group

Table G.7: Estimated average adult upriver survival from Bonneville to Lower Granite, by release group ($S_{A_{Rel}}$). Estimates include both transported and nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook adult upriver survival does not include the age-1-ocean age class ("jacks"), while steelhead adult upriver survival does include the age-1-ocean age class.

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Spring Chinook	CLR	0.7694	0.6854	0.7955	0.8709	0.8039	0.7850
		(0.0551)	(0.0204)	(0.0455)	(0.0233)	(0.0579)	(0.0300)
Spring Chinook	SNK	0.7987	0.7795	0.7609	0.8300	0.8084	0.7955
		(0.0274)	(0.0119)	(0.0230)	(0.0108)	(0.0161)	(0.0119)
Spring Chinook	SNB	0.7702	0.7534	0.7722	0.8299	0.8028	0.7857
		(0.0219)	(0.0103)	(0.0200)	(0.0097)	(0.0151)	(0.0136)
Summer Chinook	SNB	0.8285	0.8651	0.8194	0.8056	0.8510	0.8339
		(0.0257)	(0.0112)	(0.0269)	(0.0227)	(0.0249)	(0.0107)
Steelhead	SNB	0.7767	0.7742	0.4583	0.8519	0.7642	0.7250
		(0.0677)	(0.0328)	(0.1505)	(0.0285)	(0.0430)	(0.0685)

Table G.8: Estimated average adult upriver survival from Bonneville to Lower Granite, by release group for nontransported fish ($S_{A_{NT}}$). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook adult upriver survival does not include the age-1-ocean age class ("jacks"), while steelhead adult upriver survival does include the age-1-ocean age class.

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Spring Chinook	CLR	0.7694	0.6854	0.8738	0.8709	0.8302	0.8059
		(0.0551)	(0.0204)	(0.1079)	(0.0233)	(0.0641)	(0.0356)
Spring Chinook	SNK	0.8130	0.8495	0.7601	0.8355	0.8432	0.8203
		(0.0391)	(0.0156)	(0.0232)	(0.0117)	(0.0217)	(0.0163)
Spring Chinook	SNB	0.7971	0.8216	0.7711	0.8414	0.8430	0.8149
		(0.0287)	(0.0137)	(0.0204)	(0.0105)	(0.0194)	(0.0137)

Table G.8 (continued)

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Summer Chinook	SNB	0.8285	0.8626	0.9000	0.8056	0.8550	0.8503
		(0.0257)	(0.0115)	(0.0949)	(0.0227)	(0.0256)	(0.0160)
Steelhead	SNB	0.7767	0.7742	0.4583	0.8518	0.7642	0.7250
		(0.0680)	(0.0328)	(0.1505)	(0.0285)	(0.0431)	(0.0685)

Table G.9: Estimated average adult upriver survival from Bonneville to Lower Granite, by release group for fish transported at LGR ($S_{A_{LGR}}$). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook adult upriver survival does not include the age-1-ocean age class ("jacks").

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Spring Chinook	CLR	-	0.6853	0.7822	-	0.7290	0.7322
		(-)	(0.0205)	(0.0498)	(-)	(0.1263)	(0.0280)
Spring Chinook	SNK	0.7803	0.7193	0.7609	0.7978	0.7733	0.7663
		(0.0350)	(0.0171)	(0.0230)	(0.0292)	(0.0238)	(0.0132)
Spring Chinook	SNB	0.7294	0.6899	0.7722	0.7722	0.7618	0.7451
		(0.0338)	(0.0149)	(0.0200)	(0.0258)	(0.0222)	(0.0159)
Summer Chinook	SNB	-	0.8687	0.8152	-	0.8420	0.8420
		(-)	(0.0111)	(0.0278)	(-)	(0.0295)	(0.0154)
Steelhead	SNB	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)

Table G.10: Estimated average adult upriver survival from Bonneville to Lower Granite, by release group for fish transported at LGS ($S_{A_{LGS}}$). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook adult upriver survival does not include the age-1-ocean age class ("jacks").

	Release	**Release Year**					
Species	**Area**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	0.6855	-	-	-	0.6855
		(-)	(0.0205)	(-)	(-)	(-)	(-)
Spring Chinook	SNK	0.7805	0.7190	0.7614	0.7978	0.7849	0.7687
		(0.0350)	(0.0172)	(0.0231)	(0.0292)	(0.0238)	(0.0137)
Spring Chinook	SNB	0.7296	0.6897	0.7730	0.7721	0.7658	0.7460
		(0.0337)	(0.0149)	(0.0201)	(0.0258)	(0.0223)	(0.0162)
Summer Chinook	SNB	0.8283	-	-	-	-	0.8283
		(0.0257)	(-)	(-)	(-)	(-)	(-)
Steelhead	SNB	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)

G.5 Adult Upriver Survival by Return Year

Table G.11: Estimated average adult upriver survival from Bonneville to Lower Granite, by return year ($S_{A_{Ret}}$). Estimates include both transported and nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook adult upriver survival does not include the age-1-ocean age class ("jacks"), while steelhead adult upriver survival does include the age-1-ocean age class.

	Release	**Return Year**							
Species	**Area**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**Average**
Spring Chinook	CLR	-	0.7885	0.6576	0.7335	0.8691	0.7914	0.7578	0.7663
		(-)	(0.0568)	(0.0323)	(0.0246)	(0.0228)	(0.0451)	(0.2872)	(0.0287)
Spring Chinook	SNK	-	0.8088	0.7672	0.7732	0.8316	0.8132	0.6926	0.7811
		(-)	(0.0250)	(0.0189)	(0.0154)	(0.0109)	(0.0161)	(0.0711)	(0.0204)
Spring Chinook	SNB	-	0.7797	0.7411	0.7644	0.8313	0.8055	0.7080	0.7717
		(-)	(0.0223)	(0.0143)	(0.0130)	(0.0097)	(0.0151)	(0.0591)	(0.0181)
Summer Chinook	SNB	-	0.8324	0.8847	0.8087	0.7904	0.8728	0.7500	0.8232
		(-)	(0.0275)	(0.0139)	(0.0183)	(0.0231)	(0.0241)	(0.0844)	(0.0208)
Steelhead	SNB	0.6818	0.7840	0.8372	0.8486	0.8063	0.7237	-	0.7803
		(0.0995)	(0.0374)	(0.0425)	(0.0325)	(0.0399)	(0.0626)	(-)	(0.0268)

G.6 Proportion of Total Integrated Mortality

Table G.12: Estimated proportion of total integrated mortality between Lower Granite and Lower Granite accounted for by the juvenile inriver migration (μ_J) for tagged nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook measures do not include the age-1-ocean age class ("jacks"), while steelhead measures do include the age-1-ocean age class.

	Release	**Release Year**					
Species	**Area**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	0.1209	0.1214	0.1484	0.0836	0.0842	0.1117
		(0.0234)	(0.0269)	(0.0624)	(0.0246)	(0.0380)	(0.0124)
Spring Chinook	SNK	0.0642	0.0840	0.1324	0.0648	0.0922	0.0875
		(0.0046)	(0.0214)	(0.0419)	(0.0155)	(0.0178)	(0.0125)
Spring Chinook	SNB	0.0727	0.0995	0.1378	0.0622	0.0882	0.0921
		(0.0039)	(0.0171)	(0.0377)	(0.0128)	(0.0149)	(0.0131)
Summer Chinook	SNB	0.1686	0.1281	-	0.0919	0.0727	0.1153
		(0.0197)	(0.0207)	(-)	(0.0204)	(0.0221)	(0.0211)
Steelhead	SNB	0.1450	0.3094	-	0.2401	0.1776	0.2180
		(0.0272)	(0.0225)	(-)	(0.0244)	(0.0257)	(0.0363)

Table G.13: Estimated proportion of total integrated mortality between Lower Granite and Lower Granite accounted for by the ocean life stage (μ_O) for tagged nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook measures do not include the age-1-ocean age class ("jacks"), while steelhead measures do include the age-1-ocean age class.

	Release	**Release Year**					
Species	**Area**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	0.8212	0.7988	0.8344	0.8904	0.8861	0.8461
		(0.0302)	(0.0274)	(0.0648)	(0.0249)	(0.0393)	(0.0181)
Spring Chinook	SNK	0.8890	0.8772	0.8302	0.8991	0.8788	0.8749
		(0.0158)	(0.0218)	(0.0423)	(0.0157)	(0.0184)	(0.0118)
Spring Chinook	SNB	0.8764	0.8554	0.8275	0.9035	0.8830	0.8692
		(0.0098)	(0.0175)	(0.0378)	(0.0131)	(0.0155)	(0.0129)
Summer Chinook	SNB	0.7831	0.8342	-	0.8619	0.8980	0.8443
		(0.0216)	(0.0209)	(-)	(0.0211)	(0.0226)	(0.0242)

Table G.13 (continued)

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Steelhead	SNB	0.8053	0.6353	-	0.7276	0.7727	0.7352
		(0.0327)	(0.0238)	(-)	(0.0250)	(0.0271)	(0.0369)

Table G.14: Estimated proportion of total integrated mortality between Lower Granite and Lower Granite accounted for by the adult upriver migration (μ_A) for tagged nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook measures do not include the age-1-ocean age class ("jacks"), while steelhead measures do include the age-1-ocean age class.

Species	Release Area	Release Year 1999	2000	2001	2002	2003	Average
Spring Chinook	CLR	0.0578	0.0798	0.0172	0.0260	0.0297	0.0421
		(0.0167)	(0.0059)	(0.0155)	(0.0049)	(0.0120)	(0.0116)
Spring Chinook	SNK	0.0468	0.0388	0.0375	0.0361	0.0290	0.0376
		(0.0124)	(0.0042)	(0.0041)	(0.0027)	(0.0043)	(0.0028)
Spring Chinook	SNB	0.0509	0.0451	0.0346	0.0343	0.0287	0.0387
		(0.0085)	(0.0037)	(0.0035)	(0.0024)	(0.0038)	(0.0040)
Summer Chinook	SNB	0.0483	0.0376	-	0.0463	0.0292	0.0404
		(0.0082)	(0.0033)	(-)	(0.0058)	(0.0054)	(0.0044)
Steelhead	SNB	0.0497	0.0553	-	0.0323	0.0497	0.0468
		(0.0175)	(0.0089)	(-)	(0.0066)	(0.0100)	(0.0050)

G.7 Transport-Inriver Ratios

G.7.1 Systemwide T/I

Table G.15: Estimated systemwide T/I for PIT-tagged fish (i.e., "tagged systemwide T/I," R_{SYS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook T/I does not include the age-1-ocean age class ("jacks").

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	-	1.0156	-	1.1401	3.8977	-	1.0874	1.4884
		(-)	(-)	(0.0326)	(-)	(0.0466)	(1.2759)	(-)	(0.0754)	(0.4789)
Spring Chinook	SNK	-	1.0614	1.5778	1.2792	1.2216	6.5795	1.0393	1.2020	1.5501
		(-)	(0.0479)	(0.0891)	(0.0319)	(0.0388)	(1.2303)	(0.0126)	(0.0532)	(0.3821)
Spring Chinook	SNB	-	1.1015	1.2409	1.2046	1.1587	6.1471	1.0367	1.1932	1.4654
		(-)	(0.0473)	(0.0433)	(0.0229)	(0.0299)	(1.0043)	(0.0122)	(0.0465)	(0.3518)
Summer Chinook	SNB	-	1.1008	1.8779	1.0772	1.3158	13.5077	-	1.1504	1.8897
		(-)	(0.0468)	(0.1317)	(0.0244)	(0.0354)	(4.3831)	(-)	(0.0474)	(0.7601)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Table G.16: Estimated systemwide T/I for PIT-tagged fish, had they been transported as untagged fish (i.e., "untagged systemwide T/I," R^{U}_{SYS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook T/I does not include the age-1-ocean age class ("jacks").

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	-	1.0237	-	1.2039	6.4878	-	1.1447	1.7393
		(-)	(-)	(0.0496)	(-)	(0.0665)	(2.4161)	(-)	(0.1249)	(0.7655)
Spring Chinook	SNK	-	1.0742	1.8033	1.6758	1.3648	12.7480	1.1546	1.2568	1.8766
		(-)	(0.0579)	(0.1239)	(0.0831)	(0.0618)	(2.5903)	(0.0510)	(0.0680)	(0.6139)
Spring Chinook	SNB	-	1.1252	1.3348	1.4944	1.2510	11.4368	1.1183	1.2573	1.7234
		(-)	(0.0583)	(0.0719)	(0.0610)	(0.0454)	(2.0369)	(0.0402)	(0.0623)	(0.5475)
Summer Chinook	SNB	-	1.1258	2.2206	1.1827	1.5061	29.7770	-	1.2376	2.3398
		(-)	(0.0584)	(0.1830)	(0.0576)	(0.0567)	(10.0843)	(-)	(0.0748)	(1.2138)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

G.7.2 Dam-Specific T/I

Table G.17: Estimated T/I specific to Lower Granite Dam (R_{LGR}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook T/I does not include the age-1-ocean age class ("jacks").

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	-	1.0611	-	1.5924	8.5965	-	1.5152	2.1660
		(-)	(-)	(0.1278)	(-)	(0.1521)	(3.3444)	(-)	(0.4449)	(1.0143)
Spring Chinook	SNK	-	1.2307	2.6422	2.0669	1.8489	15.3965	1.6087	1.7101	2.4477
		(-)	(0.1805)	(0.2535)	(0.1377)	(0.1260)	(3.1551)	(0.1720)	(0.1615)	(0.7807)
Spring Chinook	SNB	-	1.3943	1.7742	1.8864	1.6678	13.5109	1.4697	1.7056	2.2174
		(-)	(0.1840)	(0.1254)	(0.1105)	(0.0968)	(2.4332)	(0.1376)	(0.1496)	(0.6736)
Summer Chinook	SNB	-	1.3584	3.6415	-	2.3589	37.7047	-	1.7417	3.7747
		(-)	(0.1669)	(0.3968)	(-)	(0.1542)	(12.8628)	(-)	(0.2339)	(2.2588)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Table G.18: Estimated T/I specific to Little Goose Dam (R_{LGS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook T/I does not include the age-1-ocean age class ("jacks").

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	-	-	-	1.0070	-	-	-	1.0070
		(-)	(-)	(-)	(-)	(0.1242)	(-)	(-)	(-)	(-)
Spring Chinook	SNK	-	-	-	1.9959	1.1258	6.2857	1.1303	1.1108	1.7773
		(-)	(-)	(-)	(0.1604)	(0.1007)	(1.7051)	(0.1368)	(0.1488)	(0.5952)
Spring Chinook	SNB	-	-	0.9338	1.7206	1.0035	7.1320	1.1249	1.1553	1.5695
		(-)	(-)	(0.1350)	(0.1206)	(0.0747)	(1.5984)	(0.1149)	(0.1376)	(0.4942)
Summer Chinook	SNB	-	-	-	1.3806	-	-	-	-	1.3806
		(-)	(-)	(-)	(0.1202)	(-)	(-)	(-)	(-)	(-)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

G.8 Differential Post-Bonneville Mortality (D)

G.8.1 Systemwide D

Table G.19: Estimated systemwide D for PIT-tagged fish (i.e., "tagged systemwide D," D_{SYS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook estimates do not include the age-1-ocean age class ("jacks").

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	-	0.6228	-	0.8521	2.7447	-	0.9120	1.0736
		(-)	(-)	(0.0823)	(-)	(0.1302)	(1.6765)	(-)	(0.3473)	(0.3476)
Spring Chinook	SNK	-	0.7735	1.6242	1.6181	1.2078	5.3236	1.0462	0.9243	1.4368
		(-)	(0.2881)	(0.3588)	(0.1003)	(0.1332)	(2.0028)	(0.1265)	(0.1276)	(0.3473)
Spring Chinook	SNB	-	0.7236	1.0508	1.3902	1.0056	4.4801	0.9969	0.9484	1.2398
		(-)	(0.2364)	(0.1575)	(0.0738)	(0.0920)	(1.5212)	(0.1021)	(0.1186)	(0.2801)
Summer Chinook	SNB	-	0.9948	2.7284	0.8536	1.4550	-	-	1.2035	1.3232
		(-)	(0.3774)	(0.6989)	(0.0981)	(0.1492)	(-)	(-)	(0.2168)	(0.2672)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Table G.20: Estimated systemwide D for PIT-tagged fish, had they been transported as untagged fish (i.e., "untagged systemwide D," D^{U}_{SYS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook estimates do not include the age-1-ocean age class ("jacks").

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	-	0.6228	-	0.8551	2.7447	-	0.9120	1.0745
		(-)	(-)	(0.0823)	(-)	(0.1306)	(1.6765)	(-)	(0.3473)	(0.3476)
Spring Chinook	SNK	-	0.7735	1.6242	1.6421	1.2226	5.3134	1.0364	0.9225	1.4396
		(-)	(0.2881)	(0.3588)	(0.1080)	(0.1348)	(1.9990)	(0.1252)	(0.1274)	(0.3481)
Spring Chinook	SNB	-	0.7236	0.9640	1.3891	1.0148	4.4613	0.9908	0.9458	1.2238
		(-)	(0.2364)	(0.1451)	(0.0786)	(0.0929)	(1.5147)	(0.1015)	(0.1183)	(0.2781)
Summer Chinook	SNB	-	0.9948	2.7284	0.8536	1.4550	-	-	1.2035	1.3232
		(-)	(0.3774)	(0.6989)	(0.0981)	(0.1492)	(-)	(-)	(0.2168)	(0.2672)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

G.8.2 Dam-Specific D

Table G.21: Estimated D specific to Lower Granite Dam (D_{LGR}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook estimates do not include the age-1-ocean age class ("jacks").

	Release	Release Year								
Species	**Area**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Average**
Spring Chinook	CLR	-	-	0.6228	-	0.9149	2.7447	-	0.9120	1.0928
		(-)	(-)	(0.0823)	(-)	(0.1445)	(1.6765)	(-)	(0.3473)	(0.3497)
Spring Chinook	SNK	-	0.7735	1.6242	1.5877	1.3251	5.9617	1.1895	1.0154	1.5233
		(-)	(0.2881)	(0.3588)	(0.1107)	(0.1491)	(2.2444)	(0.1617)	(0.1438)	(0.3770)
Spring Chinook	SNB	-	0.7236	1.1548	1.3916	1.1029	4.8998	1.0969	1.0304	1.3232
		(-)	(0.2364)	(0.1743)	(0.0844)	(0.1032)	(1.6676)	(0.1273)	(0.1327)	(0.3049)
Summer Chinook	SNB	-	0.9948	2.7284	-	1.4550	-	-	1.2035	1.4765
		(-)	(0.3774)	(0.6989)	(-)	(0.1492)	(-)	(-)	(0.2168)	(0.3232)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Table G.22: Estimated D specific to Little Goose Dam (D_{LGS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean. Chinook estimates do not include the age-1-ocean age class ("jacks").

Species	Release Area	Release Year 1996	1997	1998	1999	2000	2001	2002	2003	Average
Spring Chinook	CLR	-	-	-	-	0.7398	-	-	-	0.7398
		(-)	(-)	(-)	(-)	(0.1301)	(-)	(-)	(-)	(-)
Spring Chinook	SNK	-	-	-	1.6779	0.9741	2.5445	0.8877	0.7239	1.2173
		(-)	(-)	(-)	(0.1395)	(0.1227)	(1.0616)	(0.1304)	(0.1213)	(0.2810)
Spring Chinook	SNB	-	-	0.6063	1.3877	0.8205	2.7202	0.8899	0.7765	1.0444
		(-)	(-)	(0.1190)	(0.1000)	(0.0856)	(0.9878)	(0.1095)	(0.1182)	(0.2308)
Summer Chinook	SNB	-	-	-	0.8536	-	-	-	-	0.8536
		(-)	(-)	(-)	(0.0981)	(-)	(-)	(-)	(-)	(-)
Steelhead	SNB	-	-	-	-	-	-	-	-	-
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)